Fraunhofer

FHR

FRAUNHOFER INSTITUTE FOR HIGH FREQUENCY PHYSICS AND RADAR TECHNIQUES FHR

Important milestones for the GESTRA space surveillance radar in 2020: The system's transmitter and receiver unit were transported to the final location in Koblenz in the summer. This was followed by the official inauguration and handover to the German Space Situational Awareness Center in the fall.

ANNUAL REPORT 2020

PREFACE

Dear friends and partners of Fraunhofer FHR,
dear readers,

At the start of 2020, we were looking ahead with great expectation to a packed schedule full of international trade fairs and conferences, our 10th Wachtberg Forum, and a large-scale Open House. Those plans were thwarted by covid and we were forced to replan. We created the conditions for home office for a majority of our staff, moved events online and found new ways to stay in touch with customers and employees – all in record time.

Although individual orders have fallen away, we have managed to implement our research work and projects without major cutbacks. For instance, the new GESTRA space surveillance radar was handed over to the German Space Situational Awareness Center – after five years of development and with an order volume of around 42 million euros. GESTRA was transported to Koblenz in July, and the inauguration ceremony took place in October. This logistical tour de force as well as the ceremony with high-profile representatives from research, science, defense and politics is covered on page 8.

Our new digital formats have been successfully developed. One example is the Radar in Action online lecture series, in which our scientists give application-oriented presentations of the Institute's latest research results. The half-hour lectures with demonstration and discussion in German and English are met with great interest in industry, politics, science and society. They are attended by over 100 participants from all over the world on a regular basis.

We also managed to move into Villip 2 on schedule; despite covid. The new building at the Villip site was completed in June and subsequently became home to our interdepartmental Signal Processing Think Tank. The Institute continues to grow and the new facilities are enabling this through modern offices and laboratories. Among other things, the large hall houses three new 3D printers financed by funding from Research Fab Microelectronics Germany (FMD). These enable us to set new standards in the field of additive manufacturing.

We have presented our expertise at many international online trade fairs and conferences and exchanged ideas with the scientific community in the world's major engineering associations throughout the year. The excellence of our research is also confirmed by the awards we have received. This year, for example, Dr. Philipp Wojaczek received the Robert T. Hill Best Dissertation Award from the IEEE Aerospace and Electronics Systems Society (AESS). His work relates to projects Passive Radar & Networked RF Sensor Technology – Key Technology for FCAS and MGCS, among others (see page 28).

We hope you find the content interesting!

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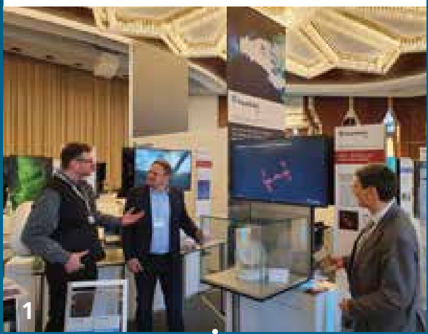
TABLE OF CONTENT

2020

Bonn, March 3-5
Applied research for defense and security in Germany


1

Wachtberg/Online, June 5
"Fraunhofer vs. Corona" Participation in the Fraunhofer-Gesellschaft #WeKnowHow social media campaign with the key technology of radar

2

Villip, June 1
Completed on schedule: New building in Villip


3

Washington/Online, April
Dr. Philipp Wojaczek receives the Robert T. Hill Best Dissertation Award of the IEEE Aerospace and Electronics Systems Society (AESS)

4

Copenhagen/Online, March 15-20
EuCAP – The 15th European Conference on Antennas and Propagation

JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE

Wachtberg, March 16
Covid-related switch to home office for about 70% of employees


8

Wachtberg, June 1
Ulf Herzer becomes new Head of Administration


9

Wachtberg/Online, June 23
Fraunhofer FHR launches "Radar in Action"
Research thrives on exchange, but this is practically impossible face-to-face in covid times. This is why Fraunhofer FHR is launching the Radar in Action international online lecture series, in which scientists present a wide variety of the Institute's radar applications: From contactless vital sign detection through space observation and autonomous driving. The half-hour presentations with demonstrations and discussions in German and English are met with great interest by customers, partners and interested parties from industry, politics, science and society. These public events are attended by over 100 participants from all over the world on a regular basis.


10

Washington/Online: April 27-May
IEEE International Radar Conference

Wachtberg/Online, April 16
Online through the ball: Premiere of online visitor tours through TIRA

Wachtberg/Online, June 22-25

ORAS final presentation

A special event: The final presentation of ORAS (sensor-based monitoring and alerting system for the detection and tracking of unmanned aerial systems) was delivered under the constraints of the coronavirus pandemic. It was attended by just a few representatives on site, including project sponsor VDI-TZ. Technical University of Applied Sciences Wildau and associated partners such as BKA (the Federal Criminal Police Office) and state police forces dialed in via live stream. The associated project partners provided further information during interviews and a Q&A session. Despite the hybrid format, the demonstration was carried out with no glitches and the system in use was presented successfully.

5

Munich/Online, October 26-29

Fraunhofer Solution Days

The Institute presents the ATRIUM radar target simulator

7

Wachtberg, September 17

Expert discussion on strategy – First event with external experts in the new Villip 2 building

6

Wachtberg/Koblenz, June 25-July 1

Logistical tour de force: Transporting GESTRA to Koblenz (see pg. 8)

Florence/Online, September 21-25

IEEE RADAR Conference

Prof. Peter Knott gives keynote speech

Warsaw/Online, October 5-8

International Radar Symposium IRS

JULY **AUGUST** **SEPTEMBER** **OCTOBER** **NOVEMBER** **DECEMBER**

Wachtberg/Online, September 5

Digital Education Fair

Koblenz, October 13

Ceremony: GESTRA inauguration in Koblenz (see pg. 10)

13

Wachtberg, November 4-5

2nd Fraunhofer FHR UAS Workshop

High-profile speakers discuss current developments on Unmanned Aerial Systems (UAS) with participants from research, industry, authorities and associations.

14

Wachtberg/Online, June 25

Hybrid Board of Trustees meeting livestreamed to all employees

11

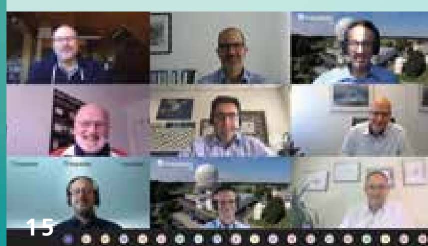
Warsaw/Online, October 5-8

Manjunath Thindlu Rudrappa wins IRS Young Scientist Contest

12

Wachtberg/Online, November 12

Virtual strategy audit



15

Berlin/Online, May 13 - August 15

ILA Berlin: Prominent trade fair appearance with TIRA and GESTRA

GESTRA MILESTONES 2020

Transportation to Koblenz

Developed by Fraunhofer FHR on behalf of the German Space Agency at DLR (German Aerospace Center), the GESTRA (German Experimental Space Surveillance and Tracking Radar) space surveillance radar completed major steps in 2020. It is currently undergoing final integration at the new Koblenz site.

7 days, 100 tons, 200 kilometers:
A logistical tour de force

The morning of June 25, 2020 marked the beginning of a perfectly planned project on Fraunhofer FHR's Wachtberg campus, the likes of which the Institute had never seen before: Loading the GESTRA system and transporting it to its final location at Schmidtenhöhe in Koblenz. Weighing almost 100 tons and measuring 4 m x 4 m x 18 m each and comprising the transmitting and receiving module as well as both radomes with a diameter of 5 m, a height of 4.50 m and a weight of 600 kg each, the two containers were ready for transport. After one day of pure preparation time, the containers and radomes were loaded onto the trailers over the next two days through perfectly coordinated teamwork by the Fraunhofer FHR staff and the logistics company. This required two cranes with maximum lifting capacities of 350 t and 500 t respectively, whose combined forces were required to lift the heavy weight of the radar systems off the ground onto two 13-axle trailers. The heavy load got on the road on schedule at 10 p.m. on June 29, 2020. As well as many vehicles for safeguarding, the convoy was also accompanied by several police vehicles. Since the loaded containers including the trailer were significantly higher than 4.50 m, some highway bridges on the A3 would have been too low and the entire journey had to be made almost exclusively on country roads. In the middle of the night, around 1:30 a.m., the convoy crossed over the Rhine via the Bonn South Bridge. It then entered the Westerwald region. The second stage with a total distance of about 200 kilometers was completed the following night, finally leading to the destination. GESTRA was awaited there by representatives of the German Space Agency at DLR, the Federal Armed Forces and Fraunhofer FHR, as well as numerous media representatives. The two heavy-duty cranes were ready so that both containers and the radomes could be assembled at the destination in front of the spectators the same day.

A special kind of move: GESTRA is relocated from Wachtberg to Koblenz over 7 days and nights. Via heavy transport over a 200 km route through the Westerwald region, the two 100 t containers together with the radomes arrive at Schmidtenhöhe safe and sound.

Research & Science, Defense and Politics: Grand Ceremony for GESTRA Inauguration

On October 13, 2020, GESTRA was officially inaugurated and handed over to the German Space Situational Awareness Center. High-profile representatives from DLR, the Fraunhofer Society and defense and politics were in attendance. During a ceremony at Schmidtenhöhe, the speakers acknowledged the significance of GESTRA for Germany and Europe and the achievements of the project participants in the development of this cutting-edge technology. Speakers included Chairman of the German Space Agency at DLR Dr. Walther Pelzer; Aerospace Coordinator of the German Federal Government Thomas Jarzombek (MdB); Fraunhofer Executive Board Member Prof. Ralf Boris Wehrspohn; Commander of the Air Operations Command (ZentrLuftOp) GenLt Klaus Habersetzer; and Interior Minister of Rhineland-Palatinate Roger Lewentz. "Through this project, we are setting Germany apart as a location." GESTRA project manager at DLR Dr. Thomas Eversberg praised the research and development work on the space surveillance radar: "Based on our state-of-the-art systems, we are in a position to work right at the forefront of science".

After the speakers symbolically cut a ribbon to mark the opening, the guests and numerous media representatives present were able to see GESTRA for themselves. "This radar system is a piece of technology that is unique in Europe," Prof. Dirk Heberling emphasized during the event, also highlighting the special attachment which Fraunhofer FHR staff feel towards GESTRA. "I remember when the containers were delivered, employees pulled and grabbed the cables with their own hands, and that was on the weekend. This shows their commitment and passion for this project," said Prof. Heberling.

The media response to the unveiling of Germany's first space surveillance radar was huge, with print, TV, radio and social media reporting nationwide. Even the Tagesthemen news program ran a report. An exciting short film by Fraunhofer FHR summarizes the highlights of the GESTRA inauguration. The film is available at https://youtu.be/bT-olld89Qs.

GESTRA was ceremonially inaugurated under tight covid restrictions. Guests from research & science, defense and politics took the opportunity to listen to on-site explanations of the system and gained a deep insight into the capabilities of the space surveillance radar.

Dipl.-Ing. Helmut Wilden,
GESTRA project manager at Fraunhofer FHR

THREE QUESTIONS TO...

Mr. Wilden, a 34-strong team has poured over 5 years of development work into GESTRA. What was the biggest challenge during this time in your opinion?

Coming from the experience with multifunctional small radars, we were suddenly faced with the task of compiling a wish list of innovative capabilities and performance data of a space surveillance radar under the constraints of partial mobility, flexibility of a digital radar and maximum transmission power, and to design and offer the most innovative technologies for each subsystem. A major challenge in this effort was in hiring highly specialized personnel, many of whom were brought on board through the supervision of theses with system-related topics, under time constraints. This resulted in a 34-strong team which, together with the development teams of the approx. 8 main subcontractors, designed and implemented an extremely complex, multifunctional system based on effective management. The greatest challenge was to achieve and implement all system specifications through hardware, firmware and software optimizations in such a way that all necessary system components were available on time while also ensuring that the expected service life of the system of 12 years could be achieved through robust conceptual design.

What was your personal highlight?

I experienced several personal highlights during my 6 years leading this team. On the one hand, I was very pleased with the students' commitment and enthusiasm to produce very good thesis results on the system-related topics. Transporting the system, where the constraints could only be mastered by a very experienced transport team, was definitely another highlight. Of course, the greatest joys of this development story were the final commissioning and then gradually building up proof that the performance targets were being met.

How do you let go of a project like this?

Thanks to my hobbies in crafts and music, I can let go of this project with relative ease. However, the various alternative design concepts of the individual subsystems, including signal processing, will keep my mind occupied and motivated for the rest of my days! We achieved a good starting performance with this radar demonstrator. Nevertheless, the detection performance against small debris could still be much better under the same constraints with the use of even more innovative and challenging technologies.

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MENELAOS^{NT} DOCTORAL PROGRAM

The European Training Network on Multimodal Environmental Exploration Systems – Novel Technologies (MENELAOS^{NT}) stems from an initiative of Prof. Dr. Otmar Loffeld from the Center for Sensor Systems at the University of Siegen (ZESS). Dialog with Fraunhofer FHR led to the idea of establishing a collaboration between renowned European institutions in the field of Compressed Sensing. After several years of planning, the program was initiated on January 1, 2020. MENELAOS^{NT} is funded by the European Union's Horizon 2020/Marie Skłodowska-Curie Actions research and innovation program. It provides 15 international early stage researchers with the opportunity to progress to a PhD via research on various algorithmic and hardware-oriented tasks.

Fraunhofer FHR is one of the collaborating partners of MENELAOS^{NT} and is supervising two early stage researchers based in the High Frequency Radar and Applications (HRA) and Cognitive Radar (KR) departments. Sanhita Guha works at HRA, Saravanan Nagesh at KR. Both of them will also spend several months conducting research at the Weizmann Institute of Science near Tel Aviv, as well as at the University of Siegen and the Polytechnic University of Bucharest as part of their three-year doctoral programs.

The program comprises specialized lectures and courses at the partner universities, which take place online. In addition, the up-and-coming scientists are offered face-to-face workshops at their institutes on topics such as scientific writing, communication skills, job application strategies, networking at conferences, etc. Dr. Andreas Bathelt of HRA is the program coordinator at Fraunhofer FHR. "It is great to see the results the PhD students are achieving in the program. Compared to the usual tasks of the institute, whose focus is more on the application of methods in for example industrial projects, the Horizon 2020 MSCA grant allows our ESRs to work independently from this focus. They work independently, unlike industrial projects, for example, where the focus is always on the application for the partners. Therefore, they can go much more into the details depth and design new methodologies themselves. MENELAOS^{NT} envisages that the PhD students' results will also be used further later on, definitely by the Institute," says Andreas Bathelt.

SANHITA GUHA

"I first completed a Bachelor's degree in electronics and instrumentation technology in Bangalore, India. Then I went to France to the Georgia Institute of Technology in Metz. I completed my Master's degree in Electronic and Computer Engineering there, graduating in May 2020. I came across MENELAOS^{NT} while looking for an interesting PhD program. I am now doing research in the HRA department at Fraunhofer FHR for my PhD on "Adaptive methods of Compressed Sensing for more efficient Radar Detection and Localization". I am working on methods that can increase the resolution of narrow-band radar systems using band fusion. I am very pleased to be collaborating with Dr. Andreas Bathelt as my Supervisor, with Prof. Dr. Joachim Ender and Prof. Dr. Loffeld supervising my PhD. MENELAOS^{NT} is a comprehensive program, where I hope to learn a lot. I like networking with different professors in Europe, the conference opportunities, the possibility to improve my soft skills and German language skills. I would also like to work in the field of Compressed Sensing after my PhD."

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SARAVANAN NAGESH

"After completing my Bachelor's in Electronics and Communications in Bangalore, India, I worked as a research fellow at the Center for Airborne Systems, in the area of airborne communication and radar systems. Later, I joined Robert Bosch as a senior engineer in the area of vehicle safety systems for the Asia-Pacific region. Since, I was interested in learning more on Radars, I chose to pursue a Master's degree in electrical engineering, majoring in radar signal processing at the Technical University of Delft, in the Netherlands. The MENELAOS^{NT} program consisted of a well-structured career development plan with opportunities to work in top R&D establishments, this motivated me to join Fraunhofer FHR as an Early Stage Researcher at the KR department. My PhD supervisor is Prof Dr. Joachim Ender and Dr María González-Huici as the supervising advisor. My study focuses on the design of "Coded Waveform for Colocated MIMO Radar using Sparse Modeling". I am excited about the opportunity to work on cognitive automotive radars and look forward to learning German. I trust my work, may one day contribute to reduce road fatalities."

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DOCTORATE AT FRAUNHOFER FHR

Fraunhofer FHR offers scientists optimal conditions for writing their dissertations at the Institute. In doing so, the Institute provides each one of the employees with support that is precisely tailored to their individual interests and routes to the PhD. Two employees who completed their doctorates in 2020 report on their experiences.

DR. FABIO GIOVANNESCHI

"Online Dictionary Learning for Classification of Antipersonnel Landmines Using Ground Penetrating Radar"

University of Siegen

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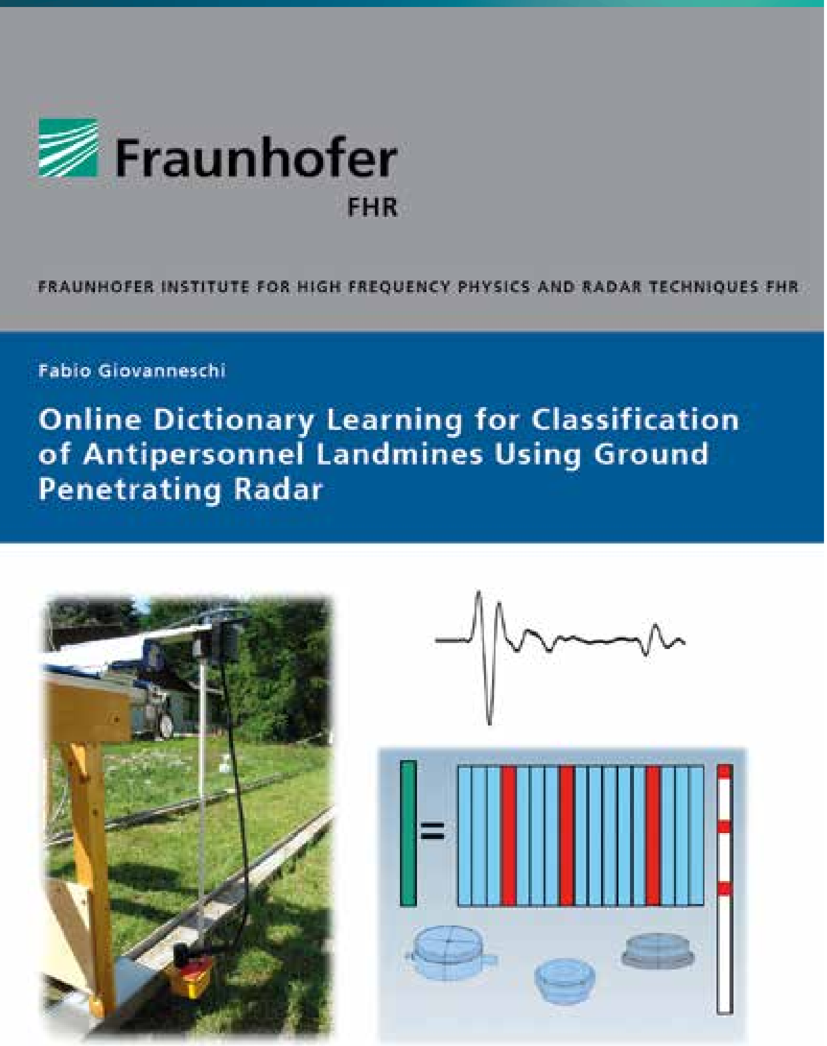

Dr. Fabio Giovanneschi began his work in the present-day Cognitive Radar (KR) department of Fraunhofer FHR in 2012. He had previously studied telecommunications engineering at the University of Pisa and then worked at an Italian company in the field of geophysics for two years. At Fraunhofer FHR, he was involved in anti-personnel mine classification using Ground Penetrating Radar (GPR). "I also became interested in the Compressive Sensing theory, which was relatively new at the time, and started to apply it to my work with GPR. I wanted to dedicate my PhD to this exciting new area."

Prof. Joachim Ender, who was head of the Institute at the time, was very interested in the topic, so Dr. Fabio Giovanneschi was accepted onto the PhD program at the Center for Sensor Systems at the University of Siegen (ZESS) in 2014, with Prof. Ender as the first supervisor of the PhD thesis. In the following years, however, he initially worked intensively on other KR projects as well as for the RAWIS (Radar Warning and Information System for Applications in Disaster Management) project at the University of Siegen. "I came into contact with Prof. Yonina Eldar from Technion Israel in 2016. A fruitful collaboration started on the basis of my idea to develop novel dictionary learning technology targeting a cognitive approach to the mine classification problem with GPR. This led to the publications which form the main contribution of my PhD thesis." Since completing his PhD, Dr. Fabio Giovanneschi has continued his research in dictionary learning and applied it to various radar applications, such as marine clutter suppression and LIDAR imaging.

"The collaboration with Prof. Ender is always motivating and inspiring to me. Moreover, Dr. Stefan Brüggenwirth as department head and Dr. Maria Antonia Gonzalez-Huici as team leader have always supported the research for my doctoral thesis. The colleagues in Wachtberg were also happy to engage with me and exchange ideas throughout all those years," Dr. Fabio Giovanneschi recalls.

After studying electronic engineering with a focus on information and communication technology at RWTH Aachen University, Dr. Christoph Wasserzier joined Fraunhofer FHR as a researcher in 2009. "At first, the doctorate was not my plan in the first place. Instead, I focused on exciting tasks in the present-day Passive Radar and Anti-Jamming Techniques (PSR) department, in areas where the publication of the research results is somehow difficult."

The idea to pursue a doctorate originated from a growing interest in the field of noise radar. "The topic has always seemed promising to me and has reached great potential in terms of its practical applicability enabled by recent technical developments. That was appealing to me."

Dr. Christoph Wasserzier attended the PhD program at the Tor Vergata University of Rome starting in 2016. He was supervised by Professor Gaspare Galati, who has a vast experience as a researcher in this field. He traveled to Rome particularly for block seminars, but a bulk of interaction with Professor Galati took place online. "The program's clear structure allowed me to work efficiently and to combine the doctorate and activities at the Institute smoothly. My team leader Josef Worms, Prof. Daniel O'Hagan as head of department and his predecessor Heiner Kuschel always supported my PhD. Many colleagues from PSR or the workshop helped actively, especially during field experiments."

Dr. Christoph Wasserzier developed a new, real-time capable method enabling future applications in noise radar. The demonstrator he implemented in order to experimentally prove the method was received with great interest. Subsequent uses included a NATO measurement campaign and it will continue to be used by PSR in the future. "Fraunhofer FHR provides the best conditions for successful research, not least due to the great infrastructure and equipment of the laboratories as well as the high level of technical competence of the employees. But the close collaboration with the Federal Armed Forces is what enabled the high quality of the results in the first place," he sums up the conditions of his PhD.

DR. CHRISTOPH WASSERZIER

"Noise Radar on Moving Platforms"

Tor Vergata University of Rome

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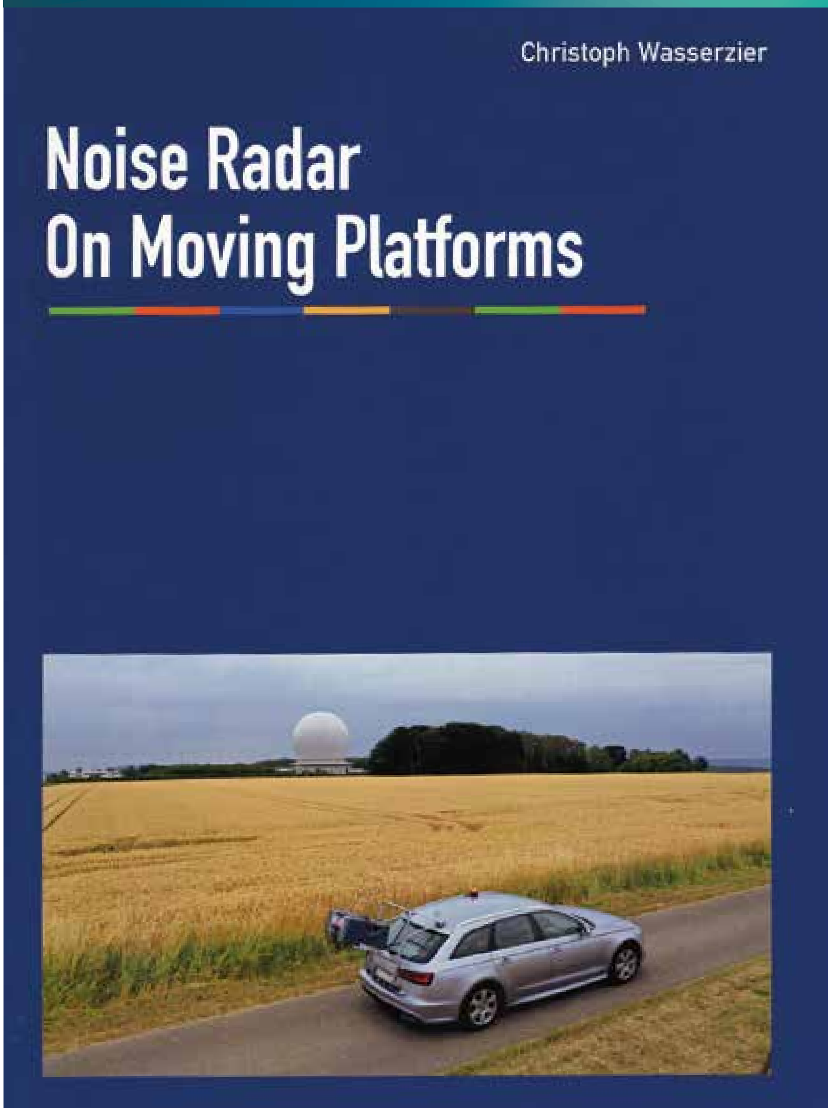

FRAUNHOFER FHR IN PROFILE

Fraunhofer FHR is one of the leading and largest European research institutes in the area of high frequency and radar techniques. It develops customized electromagnetic sensor concepts, processes, and systems for its partners, from the microwave range through to the lower terahertz range.

The core topic of the research at Fraunhofer FHR consists of sensors for high-precision distance and position determination as well as imaging systems with a resolution of up to 3.75 mm. The applications range from systems for reconnaissance, surveillance, and protection to real-time capable sensors for traffic and navigation as well as quality assurance and non-destructive testing. Fraunhofer FHR's systems are characterized by reliability and robustness: Radar and millimeter wave sensors are suitable for demanding tasks, even under rough environmental conditions. They work at high temperatures, with vibrations, or under zero visibility conditions caused by smoke, vapor or fog. Thus, radar and the related high frequency systems, are also key technologies for defense and security. In this area, the Institute has been supporting BMVg (the German Federal Ministry of Defense) since the Institute was founded in 1957.

On one hand, the processes and systems developed at Fraunhofer FHR are used for research of new technology and design. On the other hand, together with companies, authorities, and other public entities, the Institute develops prototypes to unsolved challenges. The special focus here is on the maturity of the systems and their suitability for serial production to ensure a quick transformation into a finished product in cooperation with a partner. Thanks to its interdisciplinary positioning, the Institute possesses the technical know-how to cover the entire value creation chain, from consulting and studies up to the development and production of pilot series. The used technology ranges from the traditional waveguide base to highly integrated silicon-germanium chips with a frequency of up to 300 GHz.

The ability to carry out non-contact measurements and the penetration of materials open up a range of possibilities for the localization of objects and people. Thanks to the advances in miniaturization and digitalization, the high frequency sensors of Fraunhofer FHR with their special capacities are an affordable and attractive option for an increasing number of application areas.

Staff and budget development

The Institute's budget comes from several sources of financing: The basic financing from BMVg, the project financing through funds from the defense budget and the income from the contract research area (Vfa), which in turn can be subdivided into economic revenues, public revenues, EU revenues and the basic financing by the federal government and the federal states. In 2020, in its defense and civil segments, Fraunhofer FHR generated total income of €38.0 million.

Fraunhofer FHR had a total headcount of 390 at the end of 2020. Of these, 207 are permanent employees and 129 are temporary. The 54 remaining employees are students and apprentices.

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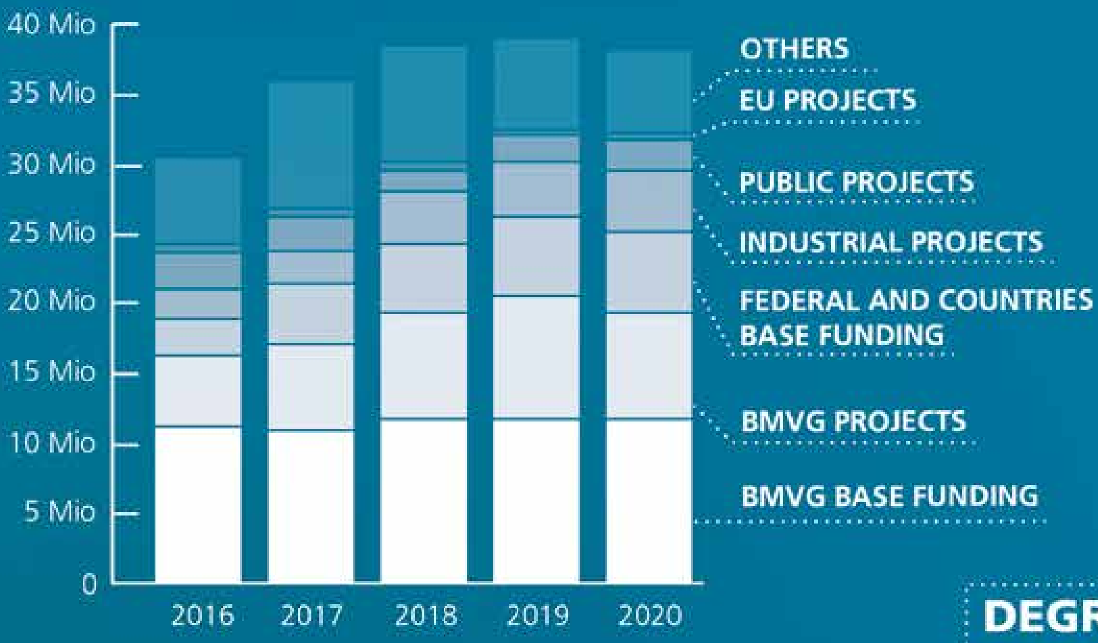
FRAUNHOFER FHR IN NUMBERS

BUDGET DEVELOPMENT



LECTURES

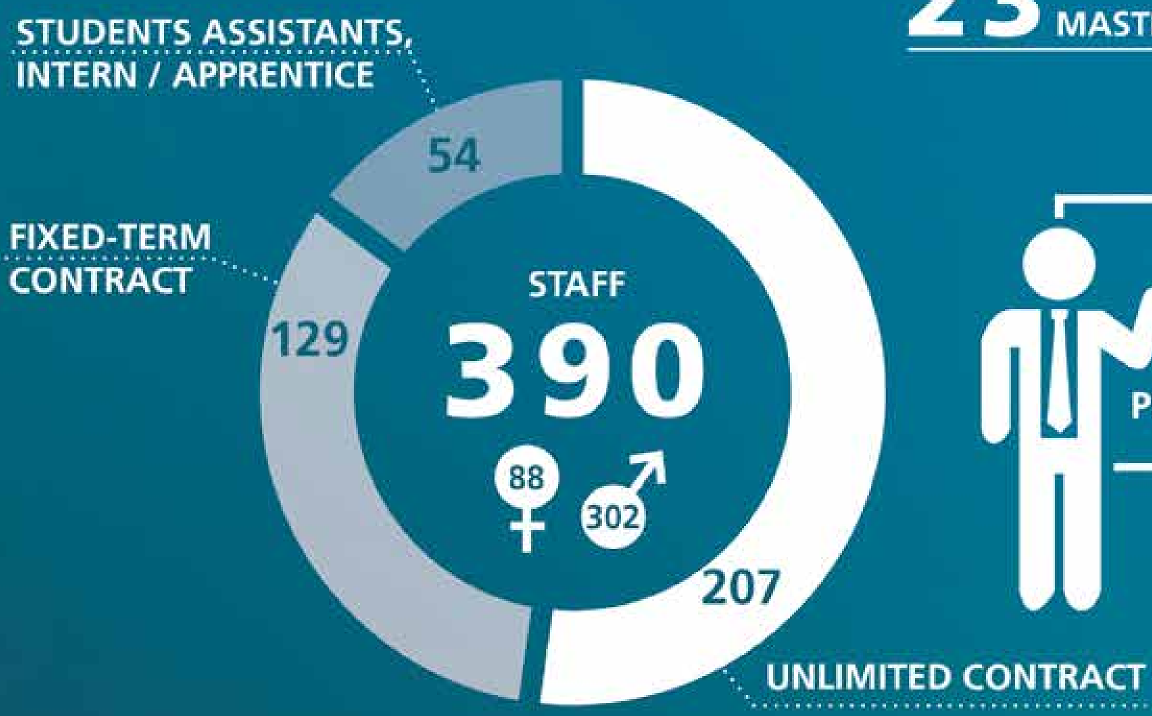
WS 19/20 **15**

SS 20 **11**

DEGREE THESIS

23 MASTER

PHD **4**



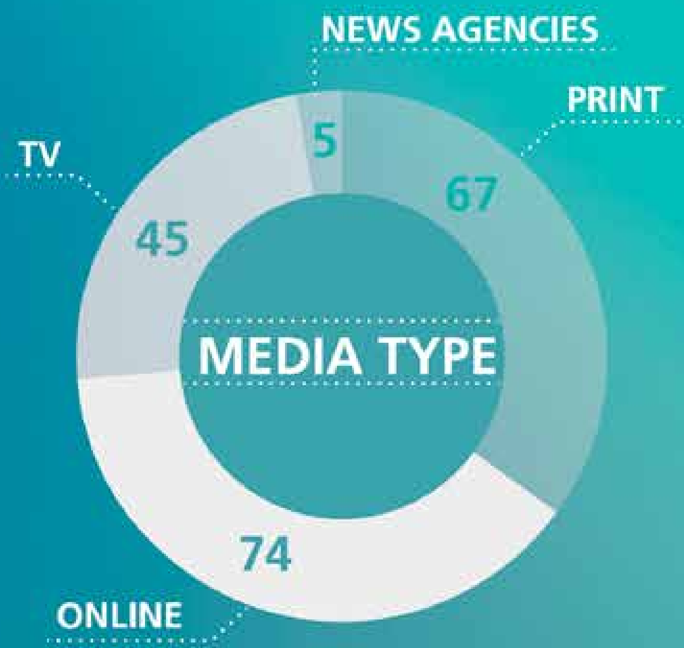
4

PROFESSORSHIP

MEDIA ANALYSIS

191 ARTICLES IN THE MEDIA

179 Mio. REACHED CONTACTS



"RADAR IN ACTION" ONLINE LECTURE SERIES:

ONLINE LECTURES **20**

96 PARTICIPANTS PER LECTURE ON AVERAGE

TOTAL PARTICIPANTS **812**

EVALUATION OF PARTICIPANTS **93%** VERY GOOD OR GOOD

German **1608**
English **1525**

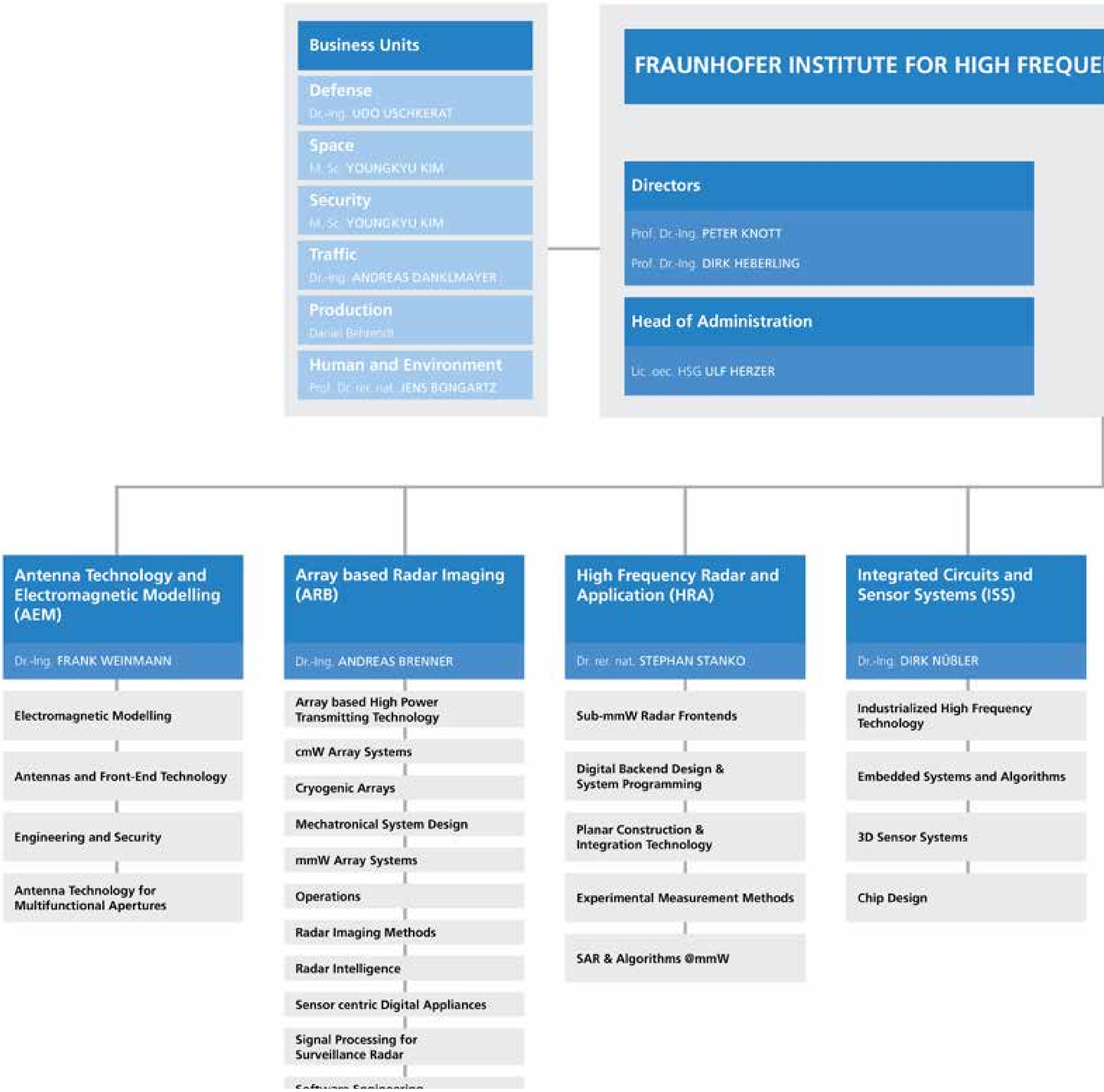
1095

1130

1589

179

ORGANISATION CHART



NCY PHYSICS AND RADAR TECHNIQUES FHR

Institutes Locations

Headquaters: Wachtberg

Secondary Locations: Aachen, Bochum, Siegen

RWTH Aachen

Institute of High Frequency Technology
Director: Prof. Dr.-Ing. DIRK HEBERLING

Research Group Aachen

Dr.-Ing. THOMAS DALLMANN

Research Group Bochum

Prof. Dr.-Ing. NILS POHL

Research Group Siegen

Prof. Dr.-Ing. JOACHIM ENDER

Staff Units

Cognitive Radar (KR)

Dr.-Ing. STEFAN BRÜGGENWIRTH

- Non Co-operative Identification
- UWB Radar
- Adaptive Sensing and Perception
- Radar Architectures
- Machine Learning for Radar Applications

Passive Radar and Anti-Jamming Techniques (PSR)

Prof. Dr. DANIEL O'HAGAN

- Passive Sensors and Countermeasures
- Passive Covert Radar
- Experimental Systems
- Passive Coherent Location

Radar for Space Observation (RWB)

Dr.-Ing. LUDGER LEUSHACKE

- Techniques for Space Observation
- TIRA Antenna System and Infrastructure
- TIRA High Frequency Systems & Radar Operations
- TIRA Signal Processing & Digital Systems Engineering
- Space Reconnaissance
- Space Situational Awareness

Administration

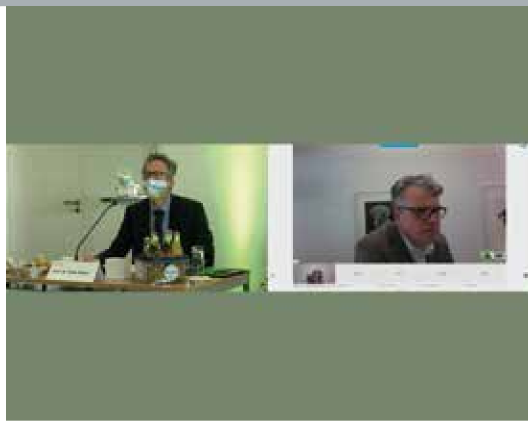
Lic. oec. HSG ULF HERZER

- Finance & Controlling
- Procurement & Equipment Management
- Human Resources
- Facility Management & Building Technology
- Information Technology

OVERVIEW


Fraunhofer


Fraunhofer FHR!




Generalinspekteur der Bundeswehr
Eberhard Zorn besucht Fraunhofer FHR


2019


Christine Mauelshagen
Fraunhofer


Neubau „Villip II": 70 Mitarbeitende ziehen gerade ein


Gunnar W. R. Pappert


Helmut Wilden
Fraunhofer

THE BOARD OF TRUSTEES

The Board of Trustees supports our research work and advises the Institute Director and the Executive Board of the Fraunhofer-Gesellschaft. The members of our Board of Trustees from industry, science and ministries are:

Due to the covid restrictions, the meeting of the Board of Trustees on June 26, 2020 was different than usual: Only a few participants attended in person, most of them were connected virtually – a first in the history of the Institute. This time, the report of the Executive Board was given by Dr. Markus Zirkel, Head of the Fraunhofer Society's Legal Department.

1 The HAGE3D allows printing with both filament and granules. The maximum print area is 1200 mm x 1200 mm x 1000 mm in 3-axis mode, while 5-axis mode allows complex components to be printed without support material, saving time and material.

2 As part of FMD, investment was made in a millimeter-wave measurement laboratory. The interior view of the anechoic chamber shows a measurement device for antenna characterization, but subsystems and complete prototypes can also be assessed.

RESEARCH FAB MICROELECTRONICS GERMANY (FMD)

Companies need perseverance for developments in the semiconductor segment: Numerous individual institutes have to be contracted. For this reason, the Research Fab Microelectronics Germany has now combined the expertise of different research institutes, including Fraunhofer FHR. Thanks to a number of new acquisitions, technologies can now be used that were not available before in Germany.

When medium-sized businesses or start-ups need developments in the semiconductor segment, they are often faced with difficulties. After all, it is rare for a single research institute to cover all required competencies. For companies, this means the following: They have to contact multiple institutes and conclude many individual contracts – a tremendous effort. This is where the Research Fab Microelectronics Germany, FMD in short, comes in: Following the example of large microelectronics institutes abroad, it combines the German competencies, establishing a joint virtual structure. The cooperation is made up of eleven Fraunhofer Institutes of the Fraunhofer Group for Microelectronics and the two Leibniz Institutes FBH and IHP. BMBF (the Federal Ministry of Education and Research) provided a total 350 million euros in funding for the creation of the FMD – in particular to close the technological gaps between the institutes and to introduce technologies which had not been available yet in Germany. Fraunhofer FHR primarily contributes its expertise in the areas of high frequency techniques, antenna measurement technology, and the production of circuit boards, radar modules, and high frequency structures.

Customers get to enjoy the direct benefits of this cooperation. They only have to contact one contact person, they receive a single contract, and they obtain the entire development chain from a single source. Let us take a radar chip as an example: For instance, the circuit design would be done by FHR, the production at IHP in Frankfurt/Oder or at Fraunhofer IAF in Freiburg, the packaging would be done at Fraunhofer IZM in Berlin, and finally, Fraunhofer FHR would have to get involved again for the radar and antenna inspection. The company would only negotiate with FMD for this entire chain.

Antenna anechoic chamber for complex radar systems

One of the key competencies Fraunhofer FHR contributes to FMD is antenna measurement technology. What are the properties of antennas for radar systems – for example, what are their directional characteristics? In the future, an antenna anechoic chamber acquired within the scope of the FMD will allow for accurate examinations of individual and array antennas in the frequency range from 300 MHz to 50 GHz. The chamber itself has been completed. The range assessment is currently still in progress – that is the verification of the test area. This involves the anechoic chamber being characterized according to specified criteria in order to be able to prove the quality of the measurements. As of late, even the smallest of antennas can be analyzed at Fraunhofer FHR using FMD infrastructure: For instance on-chip antennas, i.e. antennas with a size of one to two millimeters integrated into a chip.

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Additive manufacturing of high frequency circuit boards

Another new acquisition addresses the additive manufacturing of high frequency structures: Industrial-scale metal and plastic printers. Whereas the 3D printers we are familiar with from at home are only capable of producing small structures and low quantities, these printers make it possible to produce volumes of up to one cubic meter. Another special feature: The metal printer is also capable of printing waveguide structures. The plastic printer opens numerous new possibilities as well, for example printing antenna structures, lenses, and housings.

Producing printed circuit board prototypes at short notice

Thanks to the FMD's investment resources, FHR was able to acquire a variety of devices, including a laser milling machine, placers and bonders, to produce printed circuit boards – quickly and on short notice. This enables Fraunhofer FHR to create subsystems, e. g. for signal generation, as well as entire radar systems. To test the subsystems, the printed circuit boards are measured right inside the circuits in the high-frequency range up to 500 GHz using an on-wafer probe station . The FMD equipment at Fraunhofer FHR allows these subsystems to be measured up to one terahertz for their intended use. The equipment used for this purpose includes an anechoic anechoic chamber, which allows the characterization of subsystems, objects and materials of eight gigahertz and upwards. For example, the expected radiation power of built-up radar front ends can be checked as a function of frequency. A climatic test chamber rounds off the measurement possibilities. This allows the systems to be examined under different temperatures and humidities. With the help of various types of software, the measuring devices can be specifically controlled using certain parameters such as wave form and noise and evaluated on the receiving side. This allows Fraunhofer FHR to simulate various application scenarios for the subsystems and test them directly for specific properties such as signal linearity.

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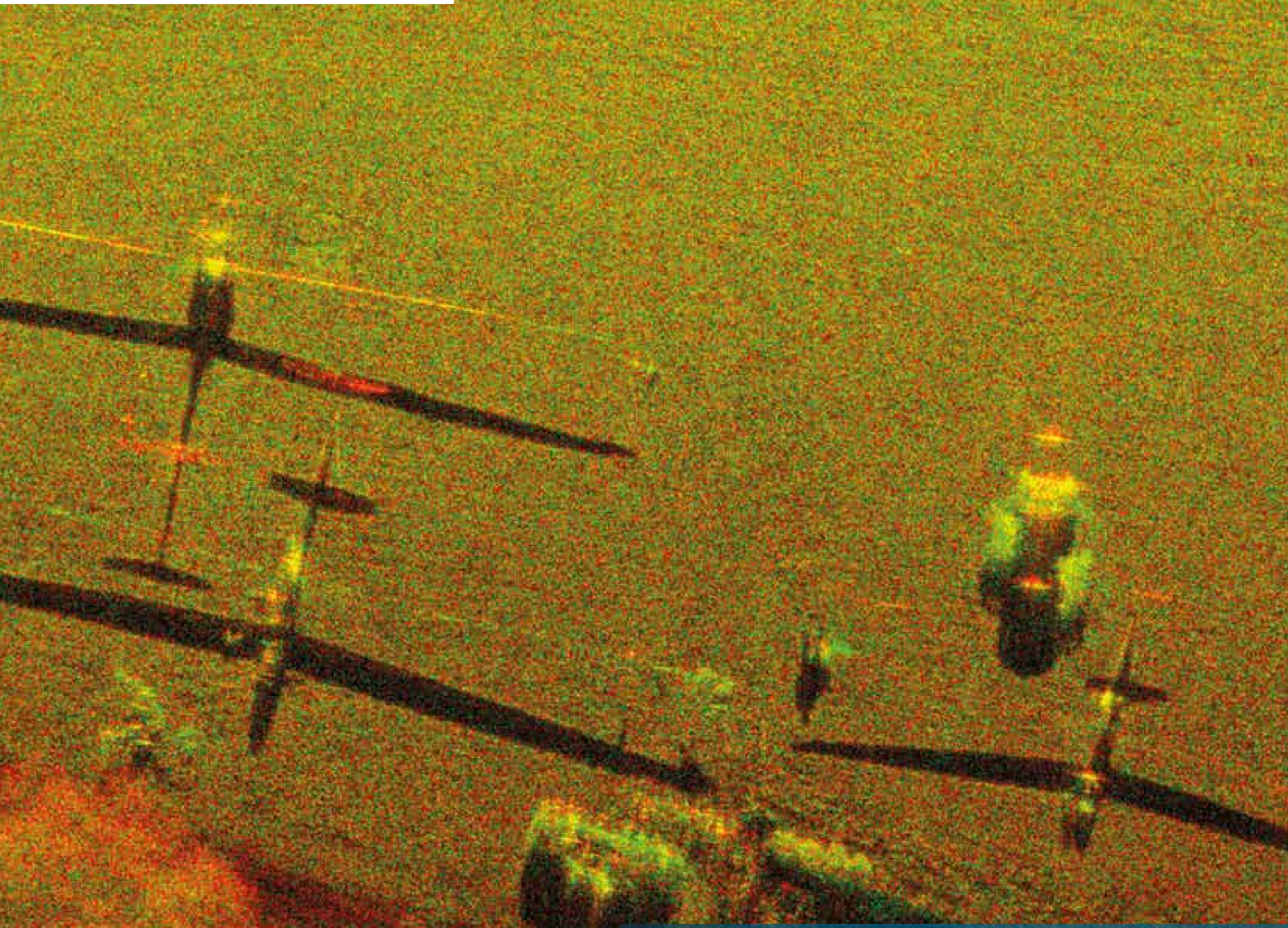

- Radar is a key technology in defense issues – traditional applications include airspace surveillance and remote imaging reconnaissance. The Business Unit Defense supports the Federal Armed Forces, among others, with its expertise in this area.

- Radar technologies can also be useful at close range, for example for the active protection of military vehicles.

- If covert reconnaissance is required, passive radar can be used to detect existing radio waves. The first passive system for air surveillance was developed and commercialized in Germany in the Business Unit Defense.

- Initial results have also been achieved in the field of cognitive radar, which performs its own parameterization.

RADAR IN THE SERVICE OF DEFENSE

Reconnaissance in crisis areas, surveillance of the airspace, protection of military vehicles: When it comes to defense, radar is a key technology – after all, it allows for the radio-based detection and measurement of objects. Fraunhofer FHR's Business Unit Defense offers a high degree of expertise in radar technologies that are frequently used by the Federal Armed Forces and the military industry.

Air space surveillance and radar imaging for remote reconnaissance

An important task of the Federal Armed Forces consists in detecting objects in airspace and low Earth orbit, whether these are aircraft, rockets, or even satellites. Therefore, the radar systems developed in the Business Unit Defense on the one hand, monitor the airspace from Earth – with the radar systems looking up into the air from the ground. On the other hand, radar systems mounted on aircraft or satellites monitor Earth from above. Such an image-based distant reconnaissance allows for the measurement of both buildings and other static objects as well as moving objects such as cars and trucks. Another task of radar systems consists in determining target classes: For example, helicopters, rockets, or similar objects are distinguished in the air, while individual buildings and even the types of agricultural areas can be recognized on the ground.

A general trend that is starting to emerge in the radar field: The use of higher frequencies is increasing. On one hand, this makes it possible to implement smaller and lighter radar systems and on the other hand, the usual frequency range is getting crowded due to increasing mobile communications and wireless networks. With its 300-gigahertz radar, the Business Unit Defense is in the big leagues on an international level.

Further radar developments for defense

Radar is also a practical solution for some close range issues as well as it is capable of imaging the surroundings even in darkness or foggy conditions. This can be important on drones or other unmanned flying objects, on robots, or on vehicles, for instance. On military vehicles, it is possible to recognize when the vehicle is being fired on: For example, when a grenade is approaching, the tenths or even hundredths of a second are crucial to be able to initiate active protection measures. The Business Unit Defense implements the radar detection of projectiles required for active protection.

Any attempts undertaken by other countries to explore the circumstances in Germany are in no way appreciated. For this reason, the Business Unit Defense also works on deceiving or jamming radar systems with the corresponding transmitters – to impede or prevent any exploration by this means. Passive radar is an ideal solution to conceal one's own observations and to thus protect them against these types of jamming attempts. In doing so, you do not emit the signals yourself but instead use the radio waves of others to monitor the airspace – without making yourself noticeable. The Business Unit Defense was also productive in applying its expertise in this area of concealed reconnaissance: It developed the passive system for air surveillance.

Cognitive radar is still a rather new field of research for the Business Unit Defense. Achieving the optimum setting of a radar system for its use is usually a complex challenge. The aim for the future is for radar to be able to carry out its parameterization itself and adapt it to the task based on its own intelligence since it makes a big difference if images of areas with high mountains or over the ocean with powerful waves have to be obtained. Excellent results have already been achieved in this area of cognitive radar. Other, still relatively new, research fields are the design of metamaterials – i.e. materials with properties that do not exist as such in nature – allowing for special features in antenna design – and coherent radar networks in which multiple transmitters and receivers work together to emit their signals so that they are finely attuned to each other.

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1 Bistatic SAR image of an airfield and a village, captured by the TerraSAR-X Earth observation satellite as transmitter and the PAMIR flying radar system as receiver.
2 HF module for synchronization of radar transmitter and remote receivers.
3 Deep-learning approach to the classification of airborne targets using radar.

NETWORKED HF SENSOR TECHNOLOGY – KEY TECHNOLOGY FOR FCAS AND MGCS

Two major projects are on the agenda at the Federal Armed Forces: Future Combat Air System (FCAS), in which a new combat aircraft including unmanned escort airplanes is to be developed, and Main Ground Combat System (MGCS), in which the development of a new tank is making strides. NATO is working on the AFSC major project. All three major projects represent complex system-of-systems requiring networked HF sensor technology – a core competence of Fraunhofer FHR.

Pilots in combat aircraft have to accomplish a lot: They have to keep the aircraft airborne and navigate while also operating and evaluating the radar more or less on the side. The Franco-German-Spanish FCAS major project therefore aims to significantly increase the level of automation in order to reduce the pilots' workload. Apart from that, it is planned that manned combat aircraft will in the future be accompanied by drones with integrated HF sensor technology, allowing significantly more situational information to be generated. The drones are equipped with radar or HF receiver systems for this purpose; combined with the aircraft, they can form a multistatic radar.

This can only be achieved using networked HF sensor technology. Such a system is being developed at Fraunhofer FHR. Networked sensors can be used to protect human lives, since the manned platform does not have to move into engagement range, while it also improves all-round visibility and optimizes reconnaissance. A multi-platform system also achieves better classification of the target, so it is much easier to determine from the images what kind of object is at hand.

Synchronization between transmitters and receivers is elementary for networked sensor technology: The systems must be fully in sync, accurate down to fractions of the wavelength – otherwise the quality of the images would be compromised. Using the new synchronization module (Fig. 2), this can be carried out via the normal radar antenna. It has also been demonstrated at Fraunhofer FHR already: A bistatic SAR image can be generated using a satellite illuminator as transmitter and the PAMIR airborne radar system as receiver (Fig. 1). Another part of the development tasks lies in intelligent signal processing and software development. This also falls under the umbrella of "cognitive radar" – after all, artificial intelligence and machine learning methods are used here (Fig. 3). And, of course, hardware is also involved, such as compact broadband and energy-efficient radar systems. Novel manufacturing processes and materials are also used for this purpose. All competencies that are necessary for the development of networked sensor technology are available at Fraunhofer FHR – the researchers work together across departments. The basic technologies required for FCAS have already been developed. Plus, unique in Germany: Fraunhofer FHR even has initial experimental prototypes of the multistatic radar already. This was used to verify the theoretical results at the Mönchsheide airfield during a measurement campaign. While two radar sensors were operated on the ground, one receiver was located on FHR's own ultralight aircraft Delphin. Another aircraft circled over Mönchsheide as a "target object".

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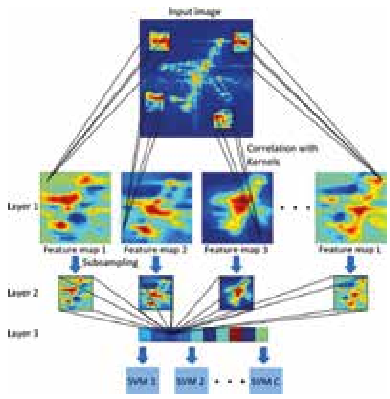

Networked HF sensor technology on the ground

Networked HF sensors are playing an increasingly important role not only in the air, but also on the ground. For instance, tanks have to withstand ever-increasing combat strength, which is why their armor is getting thicker all the time. However, this makes them heavier and heavier, so crossing bridges can quickly become difficult, and transporting them by air and ship edges towards the realm of the impossible. This is why the Federal Armed Forces is combining several small vehicles: Operating together, they should have the same combat power as a large tank, but be better protected by sensor technology. As part of the Main Ground Combat System (MGCS) project, Germany and France are developing a new battle tank envisaged in the long term as being supported by self-driving escort vehicles. However, in areas without infrastructure, communication between the vehicles poses challenges. Fraunhofer FHR is developing a solution: Using sensor technology as a means of communication at the same time.

In other current research, Fraunhofer FHR is working on improving the resolution of radar images. This can be done, for example, by having the radar systems of two vehicles look at the same point – this would significantly improve the detection capability at greater distances as well as the resolution. The resolution could also be improved immensely using a bistatic radar and stealth effects could even be evaded. Fraunhofer FHR has a great deal of expertise in this area also.

AFSC: A NATO major project

Networked sensor technology is also important in the AFSC (Alliance Future Surveillance and Control) major project. AFSC is a successor program to AWACS – this involves ground stations as well as manned and unmanned flying platforms and satellite stations. Here, too, radar systems, especially synchronization, are an important basis. A basis for which Fraunhofer FHR is developing the necessary technologies.

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1 *Polarimetric SAR image (red: co-polar, green: cross-polar) of Mönchsheide airfield.*
2 *Four-channel MIRANDA35 radar system in wingpod of Delphin ultralight aircraft showing the four receiving antennas and the transmitting antenna of the radar front end.*
3 *Ground control station with telemetry antenna in a field south of Bad Breisig during the 2020 measurement campaign.*

GERMAN-SWISS COLLABORATION: MINIATURIZED RADAR SYSTEM WITH LIVESTREAM FROM AIRCRAFT TO GROUND

Imaging techniques such as radar are extremely important for the Federal Armed Forces; airborne sensors in particular provide a great deal of information. A radar system which Fraunhofer FHR developed in a German-Swiss collaboration and is continuously optimizing can detect moving targets as well as differences in altitude. The captured data was sent directly to FHR's own ground control station during a test flight.

A picture is worth a thousand words? This saying does indeed carry some truth. The Federal Armed Forces appreciates imaging techniques too – especially the good overview from the air. Has anything in the surrounding area changed since the last overflight? Is there anything moving on the ground, for example a tank? In a German-Swiss collaboration, Fraunhofer FHR, the University of Zurich and Armasuisse are working to answer such questions as accurately as possible via radar. Their high-resolution, four-channel SAR (Synthetic Aperture Radar) allows changes to be detected, moving objects identified and even differences in altitude determined.

The system's four receiving antennas are laid out in a cross shape – data is recorded on all four channels at the same time. This allows "along track" information to be obtained, for example to detect moving targets on the ground, while at the same time recording the "cross track" data, from which differences in altitude, for example, can be detected using interferometry. In addition to the radar data, the system records optical camera images, which are also sent to the ground and facilitate the interpretation of the radar images. One of the four receiver channels is also designed for polarimetric operation: The emitted radar waves are linearly polarized in a plane. If they encounter edges, corners and similar man-made objects, their polarization direction can rotate. Valuable conclusions can, in turn, be drawn from this rotation.

Test flights with ultralight aircraft

The German-Swiss collaboration has already existed for over ten years: Fraunhofer FHR develops the hardware (MIRANDA35 radar system) and organizes the test flights, while the University of Zürich handles the evaluation. The developments are financed by Armasuisse. The newly implemented techniques have to pass a practical test once a year: Do they deliver the desired results? The system has now been scaled down so that it can be carried by Fraunhofer FHR's Delphin ultralight aircraft: To do this, all components of the radar system had to be accommodated in a small wingpod under the right wing. Staying within the Delphin's load capacity was a major challenge.

The test flights with the ultralight aircraft, starting from Mönchsheide airfield and flying over Koblenz, the Rhine Valley and the surrounding area, took place from September 21 to 24, 2020. In order to detect moving targets, the Delphin also

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flew over the Rhine ferry in Königswinter several times. A GPS transmitter on the ferry provided control values. The results are impressive: All components are fully functional and deliver the desired high-resolution SAR images.

Special features: Online SAR and dedicated ground station

The data is processed on board the Delphin in real time and sent to the ground station as image files. This is because the raw data would be far too large to be send to the ground during the flight. Such online SAR offers a considerable advantage: Operators on the ground receive the images during the overflight and can, for example, immediately signal to the pilot to fly back over an interesting spot. Another special feature: Fraunhofer FHR operates its own ground control station and is thus completely self-sufficient. From there, the radar can be controlled, the flight track managed and monitored, and data within a radius of 40 to 50 kilometers from the aircraft received. Since the station is installed in a van, it is mobile.

In a further development, Fraunhofer FHR is now working on enabling measurement at high altitudes with full bandwidth (high range resolution). The background: The radar system illuminates the ground at a certain angle. If the aircraft climbs a little, the illuminated area expands and the amount of data increases. In the future, the system will be able to deliver high-resolution images even at higher altitudes with the aid of an expansion board.

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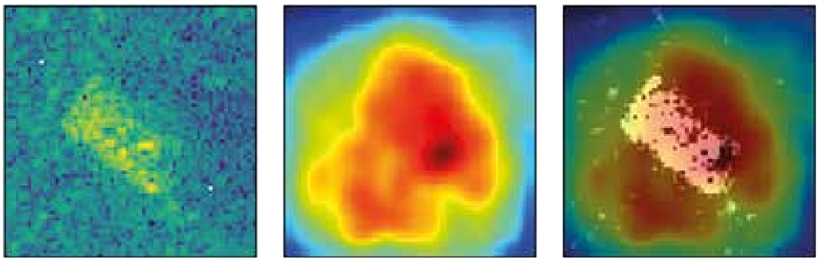

Imaging of a tank: radar data (a), heat map (b), and the comparison of the evaluated imaging locations (c).

KEEPING AN EYE ON ARTIFICIAL INTELLIGENCE

Automatic and smart data analysis is needed in many areas. This is usually achieved using artificial intelligence, which in turn is often based on neural networks. However, what exactly these neural networks do in their decision-making processes is mostly unknown. Fraunhofer FHR is now investigating the processes that were previously still in the dark.

Artificial intelligence and neural networks are hot topics that run through numerous areas – from mobility and production processes through defense. After all, the data volumes collected are becoming increasingly large, so the support needed for their evaluation is growing steadily. Although the neural networks generally deliver good results, usually it is not known how they arrive at these results. The neural networks are similar to a black box. Sometimes they rely on unimportant information when performing an image classification task. For example, in one project described in the scientific literature which involved the classification of ships in optical images, the neural networks analyzed the water instead of the ships!

Do neural networks do what they are supposed to do? Are their results therefore reliable? Researchers at Fraunhofer FHR are investigating these questions under the heading of Explainable AI. The work is based on public radar data obtained during two overflights over a field. Ten targets were placed on the field beforehand – tanks, trucks, armored vehicles and a bulldozer. The radar data generated during the first overflight was used as training data. The test data was collected during the second overflight as the targets remained untouched and only the observation angle was modified. It would thus be entirely possible for the neural networks to classify the radar images by background, such as a tree standing next to the tank.

The analysis was carried out using both feature maps and heat maps. The algorithms they use are known, but they have not yet been applied to the analysis of radar data. Visualizing feature maps at each individual layer helps to understand what the neural network learns in order to make a specific decision or prediction. The focus here is on features such as edges or the length of the target. However, in deep neural networks, this type of analysis quickly becomes confusing. This reason is that the deeper the network gets, the more complex the feature map becomes. Therefore, all important features that the neural networks "look at" were combined in a heat map in a second analysis. The results validate Fraunhofer FHR's neural networks: As desired, they analyze the targets, not the background.

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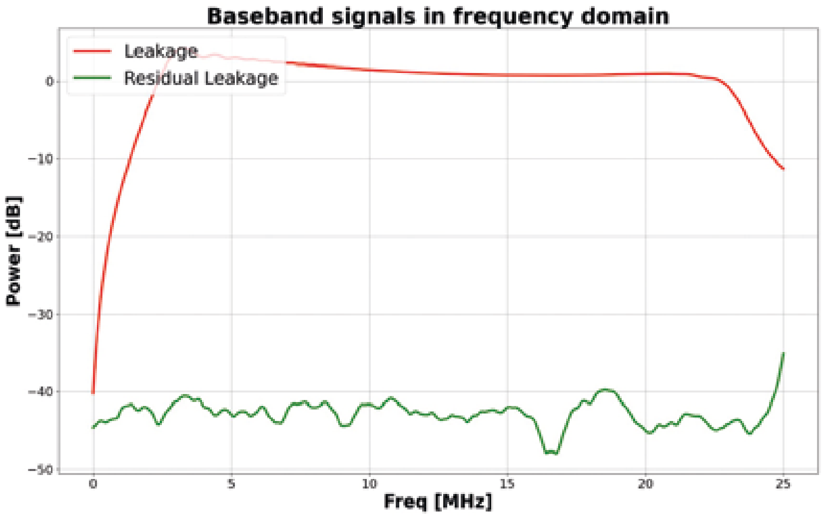

Received signal in the frequency range with (green) and without (red) RPC.

AVOID BLIND SPOTS IN THE RADAR

Whether in communications or in radar, transmission and receiving operation cannot be performed simultaneously. The reason for that is the strong transmission signal would drive the sensitive receiving amplifiers into satiation. Fraunhofer FHR is developing technologies that allow simultaneous transmission and receiving operation. Thus blind areas can be avoided using radars and for the communication sector the throughput can be doubled.

Constriction can sometimes be detrimental. For example, in radar or communications systems with their powerful transmission units and sensitive receiver stages. Only one antenna is used in these cases for reasons of cost and space. Performing a simultaneous transmit and receive at the same time is out of the question. The reason is that when the transmitting stage wants to radiate its powerful signal to the world, part of this power is coupled to the receiving branch. This quickly saturates the sensitive receivers – in the worst case, damaging it. Until now, the solution has been to operate the transmitter and receiver alternately. In communication systems, different frequencies for the transmit and receiving branches and very steep-edged filters in the front end also provide a remedy. However, this is not possible with radar. The alternating operation thus results in a dead zone – an area in front of the radar where it cannot detect any targets. This is because signals reflected from nearby objects reach the receiver while the transmitter is still transmitting and the receiver is switched off. Operators of such systems therefore want to be able to transmit and receive simultaneously.

Simultaneous operation of radar and communication

In the STAR project, Fraunhofer FHR is working to realize such simultaneous use; which is enabled by a multi-stage process. In the first stage, the instantaneous transmission signal is modified accordingly in a parallel branch and coupled into the receiving branch so that the crosstalk signal is canceled – this is also referred to as Reflected Power Cancellation (RPC). Thus, signals of any waveform can be sufficiently suppressed. A digital approach takes care of the finishing touches: It prepares the cancellation signal so that this can take place over a very wide bandwidth. A prototype has already been created and initial measurements are currently underway and shows remarkable results.

The advantage of this technology is that blind spots in the radar can be avoided. As far as communication is concerned, the data rate can potentially be doubled – assuming simultaneous transmission and receiving. Radar and communication can even be linked and their simultaneous operation enabled. After all, both require the same front end.

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BUSINESS UNIT SPACE

- The density of satellites and space debris in the low-Earth orbit is increasing rapidly. This involves increasing hazards.
- Fraunhofer FHR's Business Unit Space's TIRA and GESTRA radar systems can be used to monitor, observe and identify objects in low-Earth space. The two systems complement each other in an optimal way.
- The GESTRA radar system, which is being developed for DLR Space Management, can acquire the orbital data of numerous objects very quickly and across a large section of space at the same time.
- If an object is to be detected more accurately, the TIRA radar system is a good choice: It is already in use and can detect and image objects precisely.

SPACE: PRECISE DETECTION OF THE POSITION OF OBJECTS

Freeways and highways in metropolitan areas are not the only places where traffic density is high. Low-earth space is also very busy and sometimes crowded: It is littered with active satellites as well as space debris, and their density is increasing rapidly. Similar to road traffic, this involves increasing dangers. After all, if collisions occur, satellites can be destroyed, affecting infrastructure that is vital to society (e.g. satellites used for navigation or communications). It is therefore essential to detect, monitor and track space objects: By keeping an eye on the objects circling around at all times, in the event of imminent danger, countermeasures, such as evasive maneuvers by satellites, can be initiated in good time. Therefore, Space Situational Awareness (SSA) is one research topic that is becoming increasingly important in both the European and international context. This area of research is also gaining in significance from a military viewpoint: Suspicious maneuvers in which spy satellites approach or even dock on other satellites are on the rise. New space powers such as India and China have tested anti-satellite missiles to showcase their capabilities. The U.S. recently established a space army due to the increasing threat in and from space. France has also announced a plan to develop laser weapons for defense reasons.

GESTRA and TIRA: Hand in hand

The radar systems researched and developed by Fraunhofer FHR's Business Unit Space are ideally suited to monitoring, observing and identifying objects in low-Earth space. In this context, the TIRA and GESTRA radar systems complement each other in an optimal way. The GESTRA radar system, which is being developed on behalf of DLR German Space Agency, allows continuous monitoring in wide-range space. It can be used to determine the orbital data of many objects simultaneously. Moreover, it has the capability to determine the altitude of the objects as well as their inclination – the degree between the Earth's equator and their orbit. Another special feature: GESTRA combines phased array antennas, mechanical mobility of the radar units in three axes, and mobility of the entire system. GESTRA can thus be deployed at any location, enabling a network of radar systems for space surveillance.

If, on the other hand, a specific satellite or other space object needs to be detected with more precision, the TIRA system already in use is the system of choice. It allows satellites to be detected and imaged much more precisely – and additionally enables statements to be made about the satellite itself. If a satellite is not working, for example, TIRA can be used to clarify whether this may be due to the solar panel not being deployed correctly. The ability to image space objects in high definition using TIRA is unique in Europe, which is why the system has already supported numerous missions.

To date, the Business Unit Space has been focusing on the aforementioned space situational awareness of space objects. Other areas of activity are to be added in the future. Firstly, there are plans to supplement Earth-based SSA sensors with space-based radar. In this case, the radar system that observes the space objects is no longer located on Earth, rather on a satellite in orbit. Secondly, the portfolio is to be expanded with the inclusion of other research topics. Examples include active antenna technologies for communications satellites, SAR (Synthetic Aperture Radar) technology for Earth observation satellites and satellite-based microwave radiometers for climate and environmental research. The Business Unit Space will therefore be even more broadly positioned in the future than it has been to date, allowing other space research fields to benefit from its major competencies also.

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Diagram of radar network for space surveillance consisting of GESTRA EUSST receiver (foreground) and GESTRA system (background).

RADAR NETWORKS IN PRACTICE: GESTRA MEETS EUSST

Networks consisting of several radar units are far superior to individual radar systems. This has already been shown in a study by Fraunhofer FHR and will now be demonstrated in practice by the GESTRA EUSST project. To this end, the GESTRA space observation radar is to be coupled with a newly developed receiver called EUSST. In the future, the two systems will be spatially separated but networked to provide more precise information.

Communication, navigation, weather forecasting, television – all of these rely on satellites. If one of them fails, this can have unforeseen consequences. But such a failure is by no means improbable: After all, pieces of scrap of all kinds are buzzing around in the low-Earth orbit. If they hit a satellite, the satellite may be destroyed by the force of the impact. Satellite operators therefore have a great interest in detecting scrap particles in orbit and determining their trajectories – and triggering the satellite to execute an evasive maneuver in the event of imminent danger. This can be done by the GESTRA radar system, which Fraunhofer FHR has been building since 2014 and is currently completing. GESTRA reliably detects larger pieces of scrap. However, the system's current resolution has its limits. Therefore, even during its construction period, the consideration was: How can GESTRA's resolution be improved so that smaller "projectiles" can also be reliably detected? As a study by Fraunhofer FHR showed (see article on page 37), the answer lies in radar networks.

Practical test for radar networks

The GESTRA EUSST project, which started at the beginning of 2021, now presents the practical test: How can radar systems be interconnected in real life? The project was commissioned by DLR. The first part of the project involves building the radar system called EUSST. The second part comprises implementing the "operating system" that allows GESTRA and EUSST to work together. Finally, by combining both systems, a functional radar sensor with significantly improved resolution as well as more precise situation and orbit estimation should be produced at the end of the project. The design of EUSST is similar to that of GESTRA, but with the addition of various components which are necessary for networked operation. Also, unlike GESTRA, EUSST is intended to be a pure receiver with no transmitting unit. GESTRA is also being optimized for collaboration: In particular, the software and algorithms need to be adapted for networked operation. Another development aspect is that the time synchronization of both radar systems is required to be highly stable. This is achieved using long-term stable atomic clocks.

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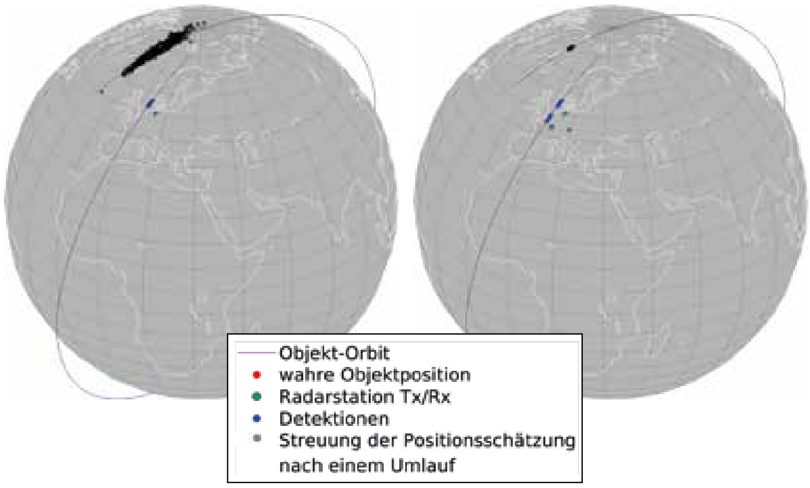

Comparison of detections and resulting scatter of estimated object position after one circuit of the orbit. Left: Single station consisting of transmitter (Tx) and receiver (Rx). Right: Multistatic network consisting of three stations (Tx and Rx).

SPACE SURVEILLANCE USING RADAR NETWORKS

We are stronger when we join forces – this is true not only for humans, but for radar systems as well. A study by Fraunhofer FHR in collaboration with Fraunhofer FKIE shows that if radars are interconnected to form networks, this increases the monitoring range, allows more precise positioning and increases the probability of detection, as the signal-to-noise ratio and thus the sensitivity can be optimized.

Is there an imminent danger of space debris colliding with a satellite? Fraunhofer FHR develops and operates various radar systems that monitor space and answer such questions. The amount of space debris is rapidly increasing and even a single screw can disable a satellite. This raises the question how space monitoring using radars can be further improved. Radar networks present one promising possibility. While radar units are located close to each other in local networks, in medium-extent networks they are located several hundred kilometers apart.

Radar networks offer numerous advantages

In collaboration with Fraunhofer FKIE, Fraunhofer FHR investigated the advantages offered by radar networks. The investigation was carried out on behalf of DLR as part of a three-year research project funded by the German Federal Ministry for Economic Affairs and Energy. The results: If the radar systems are looking in different directions, the monitoring area can be significantly increased. In contrast, if they are looking at the same object, its position can be determined much more precisely, since each of the receivers is looking at the object from a different angle. Moreover, the target velocity vector can be determined by measuring at a single point in time, whereas a single radar can only achieve this by means of observations at different times. In addition, the probability of detection can be increased using radar networks compared to the individual radar systems. This is achieved by adding up the signals from the individual radars in the network, such that the noise components partially cancel out each other, allowing for an optimization in the signal-to-noise ratio and thus an increased sensitivity.

Although the extent to which the performance of space surveillance can be increased is dependent on the objects being observed as well as the network geometry and processing, the general rule is: The more radars, the better the performance. In case of three interconnected receivers – and the ideal case of coherent processing – the detection performance improves by up to a factor of three, with four receivers respectively by up to a factor of four, and so on. Fraunhofer FHR, in collaboration with Fraunhofer FKIE, is to continue its investigations in a three-year follow-up project with DLR starting in January 2021. Among other things, the focus here will be on resource management, i.e. the question how radar networks can be operated as efficiently as possible.

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GESTRA shipping container at the final location in Koblenz.

PIONEERING WORK IN COMMERCIALIZATION

Be it the Federal Armed Forces, or telecommunications companies: Satellite operators want to protect their satellites from colliding with space debris. The GESTRA phased array radar, developed by Fraunhofer FHR, can do this. The Institute is currently working to commercialize GESTRA with an industrial partner. There is great interest both nationally and internationally.

What is buzzing around in the low-Earth orbit (LEO), and where? This question is not only interesting in itself, but also entirely relevant to our everyday lives. After all, the LEO is the orbiting location of the satellites that supply us with information – be it for navigation systems or critical infrastructures such as communications, the stock exchange and others. A lot of space debris, which poses an increasing threat to the satellites, is also floating around up there. Monitoring the low-Earth orbit and knowing what moving objects it contains requires a phased array radar with elevated beam agility. Working on behalf of the German Federal Ministry of Economics, Fraunhofer FHR has developed one of these as an experimental system. The GESTRA semi-mobile space surveillance radar was handed over to DLR and the German Space Situational Awareness Center in September 2020.

Breaking new ground: Side by side with industry

Fraunhofer FHR is now working on bringing the system into commercial use. Potential end customers, such as the Federal Armed Forces, are showing great interest in Germany's first space surveillance radar – not just nationally, but worldwide. The challenge: At present, the sensor is still at a stage where it cannot as yet be commercialized directly. Transforming this experimental system into a marketable product ready for series production requires a long-term collaboration with one or more industrial partners. Partnering with one or several German industrial enterprises would be ideal, as GESTRA is considered a safety-relevant key technology.

Fraunhofer FHR strives for a close collaboration with the partner – after all, the transfer of know-how has to be ensured. It will also accompany the development-related steps as a consultant and provider of know-how: The steps towards the finished product are to be taken side by side. As simple as this may initially sound, the commercialization of such a complex system at this scale has never occurred before at the Fraunhofer Society. As a result, there is no blueprint for the processes it requires. To a certain extent, pioneering work needs to be done here to pave the way for other large-scale projects as well. This will benefit not only research and industry partners, but also end customers, who will thus be able to access new technological developments at an earlier stage.

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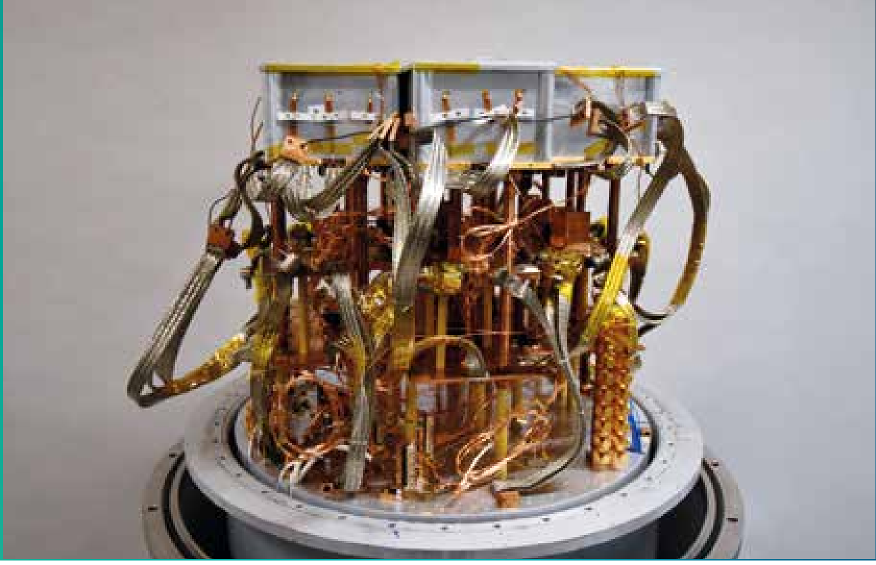

Scalable cryogenic 7-element receiver array in preparation for high frequency measurements.

HIGHER SENSITIVITY WITH DEEP-FROZEN RADAR RECEIVERS

If the smallest satellites in orbit are to be monitored or if radar is to be used to look as far as possible into space, the radar systems must have a good level of sensitivity. But weak signals are quickly masked by the inherent noise of the receivers. Cryogenic technology can help: If the receivers are cooled to four degrees Kelvin, sensitivity can be expected to double. Such a cryo-receiver is currently being developed at Fraunhofer FHR.

Thousands of cube sats are already buzzing around in low-Earth orbit – small satellites, sometimes no bigger than an orange. And the number is constantly increasing. To be able to see them with radar equipment or to look into more distant areas of space, the sensitivity of radar equipment must be continuously optimized. Fraunhofer FHR relies on cooling for this purpose: Helium is used to cool the radar receiver down to four degrees Kelvin or minus 269 degrees Celsius, four degrees above absolute zero. At these temperatures, the atomic lattices hardly vibrate at all, so the inherent noise of the receivers is also reduced. This could enable the sensitivity of radar systems to be doubled, based on theoretical calculations.

The helium coolant is conducted around a circuit. It is initially compressed using a compressor – similar to the coolant in a refrigerator – then fed to a cold head, which is placed in a vacuum container. The helium is expanded again, in this container, releasing its cold energy. Since the system is closed, the helium can hardly volatilize. There are some challenges to be overcome when building such a cryo-receiver. For one thing, a temperature difference of almost 300 degrees exists between the vacuum and the outside space – this thermal radiation has to be intercepted. Furthermore, electrical cables must be fed in from the outside, and they cannot be allowed to conduct any significant heat into the vacuum either. The third challenge lies in the vacuum container itself: Not only does it have to withstand the pressure difference between the atmosphere and the vacuum, but it must also provide thermal insulation and be permeable to certain high-frequency ranges. A compromise can be achieved via a high-frequency window. The question of which material is best suited to such a window involves many different areas of expertise, from high-frequency technology through mechanics and refrigeration technology. Since cryogenic technology has not yet been widely used in radar technology, Fraunhofer FHR is working closely with radio astronomers at the Max Planck Institute in Bonn and the CSIRO in Australia.

A first demonstrator has already been developed, and tests on temperature and pressure stability carried out. Further steps now include high-frequency measurements and determination of the system's noise figure.

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1 *The TIRA space observation radar.*
2 *Cube-Sat: Thousands of satellites this size are currently orbiting the Earth.*
3 *Man-made objects that are orbiting the Earth – mostly space debris.*

TIRA – SPACE OBSERVATION RADAR OF THE FUTURE

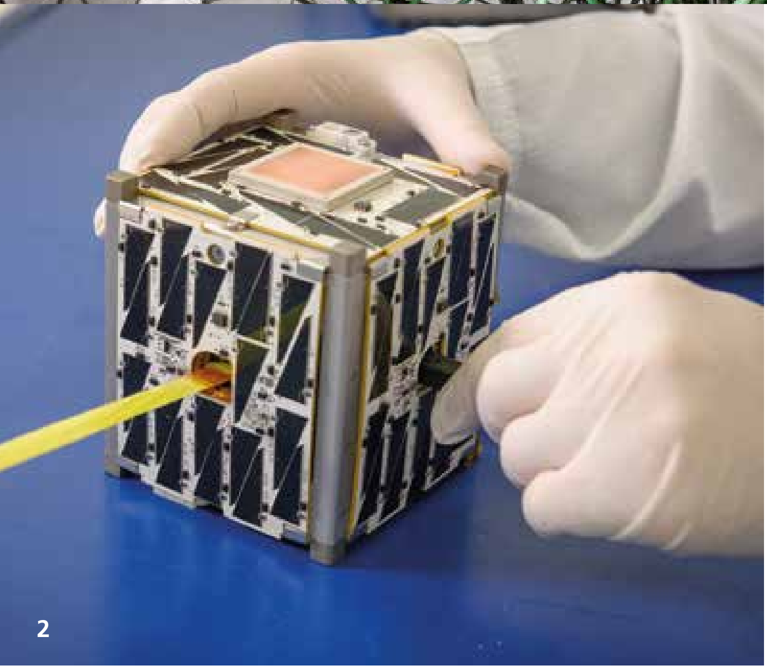
The situation in low-Earth space is changing dramatically: It is becoming fuller all the time and the satellites buzzing around are getting smaller and smaller. Space observation radars must keep pace with these developments, by meeting requirements such as higher resolutions and high sensitivity. Fraunhofer FHR's TIRA space observation radar provides an excellent basis for this and it is currently being prepared to fulfill future requirements.

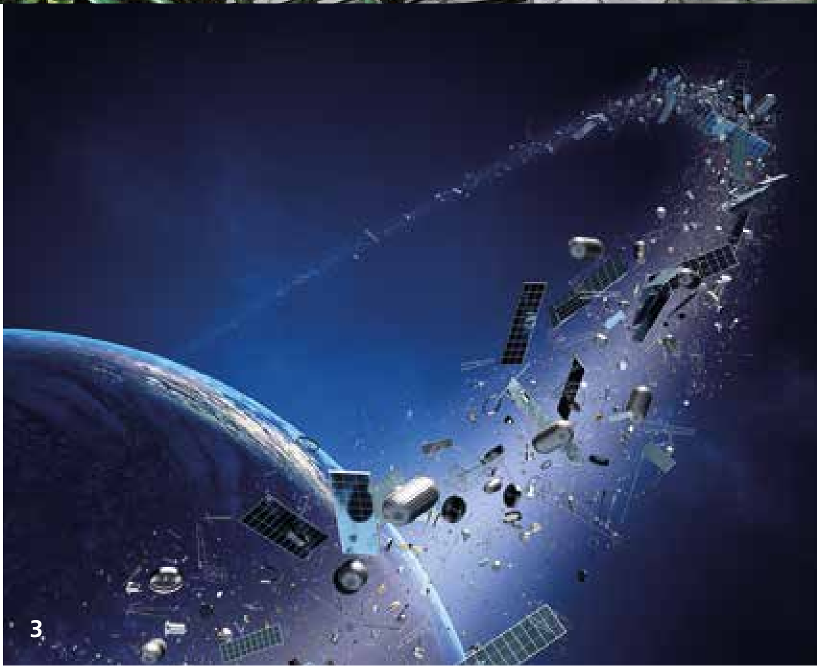
The area where most people would assume there is only empty space is becoming increasingly full. Driven by globalization, digitalization, low-cost technologies and constant miniaturization, countless satellites, both active and decommissioned, as well as an ever-increasing amount of space debris, are buzzing around in low-Earth space. In the past, the number of Earth satellites increased linearly, but now it is rising almost exponentially. While in the past only space agencies such as ESA and NASA launched satellites into space, Google and other companies are now increasingly entering the satellite business. Another development is that satellites are becoming smaller and smaller, and their attachments ever more compact. After all, small satellites are much cheaper and development times are shorter, making them easier to replace in the event of a failure. The smallest of these are the "cubesats", featuring the smallest possible unit measures of just 11.35 x 10 x 10 centimeters. The following figure shows the scale of their footprint in space: In 2017, 18,000 cubesat launches were registered for the subsequent five-year period. With such a flurry of activity in LEO – the low-Earth orbit located between 200 and about 2,000 kilometers above the Earth's surface – orderly, safe satellite operations are becoming increasingly difficult. As a result, many satellite operators are already moving to higher altitudes. However, the further the satellites are from radar, the more difficult they are to detect and image.

For high-value satellites in particular, various demands, including for mission support, are set to increase significantly in the coming years. Is some part of the satellites damaged? And if so, which? With current systems, such questions will become increasingly difficult to answer in the future.

Requirements for space observation systems

As far as the choice of space observation systems for the future is concerned, radar is ideal. This is because it offers several advantages over optical systems: Optical systems only deliver results under cloudless skies and additionally depend on the satellites, but not the sensor, being illuminated by the sun. In contrast, active radar systems work equally efficiently even under cloudy skies, in fog and haze, and day and night. However, the demands on resolution are now enormous. After all, even small satellites need to be recognizable on radar images, and not only as dots; in the future, it will also be possible to recognize details such as attachments or damage. However, this requires at least ten resolution cells per object per spatial dimension. This means that for a satellite measuring 5 x 5 x 5 meters, the resolution would have to be at least 50 centimeters.





TIRA is the only system in Europe to meet the basic requirements

The TIRA system already meets many of the basic requirements that a space observation system of the future needs. For example, it has two radar systems: A high-precision target-tracking radar that can track objects in space and an imaging radar that produces high-resolution images supported by the target-tracking radar. A key core component of TIRA is its 34 m antenna, which ensures high sensitivity. This enables a lot of energy to be radiated into space towards an object in a targeted manner and as much as possible of the energy scattered back from that object to be recovered – the basic requirement for high sensitivity. All the necessary infrastructure is also in place, including high-precision mechanics that enable the radar antenna to precisely track the space objects passing by in the sky. Furthermore, the antenna is particularly agile, which enables the tracking of space objects even when passing close to the zenith.

In short, TIRA is the only system in Europe that fulfills these basic requirements and that can therefore be expanded to form the space reconnaissance sensor of the future with relatively manageable effort. Fraunhofer FHR will meet this challenge in the coming years in order to significantly increase the information content of future TIRA radar images, thereby also enabling sufficiently good-quality imaging of small and distant space objects.

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- The attack on the World Trade Center on September 11, 2001, led to numerous national and international research programs aimed at protecting civilians in peacetime.
- Security research is based on three major pillars: Protecting people, protecting critical infrastructure, and protection against crime and terrorism.
- Among all these pillars, radar offers numerous possibilities to increase security in the civilian area.
- For example, combined with radar technology, drones can locate signs of life in people trapped in smoke-filled buildings or under rubble.

CIVIL SECURITY: WIDE-RANGING SUPPORT BY RADAR

On September 11, 2001, the attack on the World Trade Center spread fear and terror throughout the world: After all, it was the first terrorist attack of this scale on a civilian target. Further attacks followed in Madrid in 2004 and in London in 2005. Research responded: While previously there had not been any security research for the civilian sector, in the aftermath of the attack on the twin towers, numerous national and international research programs were created to address the protection of the civilian population in times of peace. One example for such a program is the German federal government's security research program "Research for Civil Security", which is currently heading into its third round. In general, security research is based on three major pillars. First: The protection of people – whether at big events, train stations, or airports – as well as their rescue, for instance in natural disasters, epidemics, attacks, or similar. Second: The protection of critical infrastructure. This includes airports, train stations, waterways, and bridges as well as energy and water supply and communications. Third: The protection against crime and terrorism. For instance, how can we deal with the fact that more and more people on the streets carry knives and even use them in trivial disputes? There are about a dozen knife attacks per day in Berlin alone! Radar offers a number of ways to increase civil security for all three of these pillars and Fraunhofer FHR's Business Unit Security is a competent point of contact.

Protecting and rescuing people: Unmanned systems with radar sensors

In a disaster, it is often difficult or even impossible for the emergency forces to quickly get a precise picture of the situation. For instance, in the event of a fire it is extremely dangerous to enter a burning building to search for people. Drones combined with radar technology can help. Drones can fly into smoke-filled buildings and locate signs of life or animals using integrated radar sensors. At the same time, radar sensors can ensure that the drones navigate safely through buildings without hitting any obstacles. This way, rescue missions would be significantly faster, more efficient, and safer. Radar sensors can also provide valuable services when searching for buried people by locating signs of life underneath the debris. In a next step, it would be conceivable to let drones work autonomously – this would provide further relief for human rescue workers. The Business Unit Security is already conducting research on this type of radar technology in a variety of directions. Cognitive radar goes even further, with the radar system independently setting the optimal parameters, fine-tuned to the current situation.

Protecting critical infrastructure: Inspection robots equipped with radar sensors

Civil security also includes discovering the smallest of cracks in power plant cooling towers, tunnel systems, bridges, or similar infrastructure. Drones and robots can take on these sometimes dangerous but also time-consuming tasks. There are two starting points for radar technology here: On the one hand, it can prevent collisions via sense and avoid. When the radar sensor detects a wall or another obstacle, the data can be sent to the drone's or the robot's control system to ensure that it avoids the obstacle. The Business Unit Security has already successfully completed the first tests. On the other hand, radar sensors offer advantages for the analysis of infrastructures – for example, they are capable of providing images exact to the millimeter and detecting cracks and damages even in dark, smoke-filled, or inaccessible environments.

Protection against crime

Radar systems are also very useful for the third pillar, protection against crime. For example, they make it possible for security forces to detect whether people are carrying knives or other dangerous items underneath their clothing without the need for contact.

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ORAS final presentation on the Institute's campus.

DRONE IN FLIGHT?

If a child is playing with a small drone in the back yard, this is not a problem. However, at political rallies or sporting events, the situation is different. In such cases, an oncoming drone can signal serious danger. The ORAS system reliably detects drones on approach, even if they are approaching through urban canyons. The system's capabilities won onlookers over during its final presentation.

Unless appropriate security measures are in place, political demonstrations can easily get out of hand, and political rallies and sporting events also need to be secured as well as possible. Emergency forces have to keep an eye not only on the people in the area, but increasingly on the airspace also. This is because a drone could approach, for example, in order to disrupt political events or to display a banner or flag without authorization at sporting events. Fraunhofer FHR and various partners have therefore joined forces in the ORAS project to develop a radar-based system for emergency services that immediately detects drones.

Successful final presentation

The system managed to show what it is made of during the final presentation. This was originally planned for April 2020 in Moosbach, but due to pandemic restrictions it had to be relocated to the Fraunhofer FHR site and rescheduled to June 2020. To minimize the number of on-site attendees, the presentation was livestreamed to partners and potential end users. Fence radars were positioned on the site fence; the camera system and the dome radar were set up 200 meters further away. Controlled from outside, a drone performed agile flight maneuvers over the FHR site: It zigzagged, flew up and down, moved close, then away again. In a first scenario, it flew over the fence radar and onto the site – equivalent to flying in through a canyon of houses. In a second scenario, it approached at a higher altitude and was first detected by the dome radar, this corresponds to flying above the roofs of houses. In both scenarios, the camera panned to the drone. The test run was successful: The system's various applications were vividly demonstrated.

In addition to the final presentation, three other BMBF-funded projects with the same goal were presented alongside ORAS in Moosbach in October. In the decommissioned barracks, ORAS was able to optimally demonstrate its strengths – for example, when flying a drone through a canyon of houses below the edge of the roof. The potential users from BOS and industry gave ORAS a positive report card, which is why FHR is striving to further develop the system with a view to commercialization.

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Emulator of the coastal radar transmitter (left) and the two antennas of the passive radar that will be mounted on the drones in the long term (right).

COASTLINES: WELL PROTECTED

External borders need to be adequately protected – including those of the European Union. In the Roborder research project, a consortium is developing an integrated autonomous system that will help the EU secure its borders in the future. As part of the project, Fraunhofer FHR is to develop a passive radar which, when placed on drones, can increase the range of the coastal radar by up to 20 percent.

The European Union has a great interest in protecting its external borders against illegal immigration – for example at the Mediterranean Sea. How can this border protection be optimized? This question is being investigated in the Roborder EU consortium project by 26 partners from science and public institutions including Fraunhofer FHR. The development goal is an integrated autonomous system that includes flying, swimming, driving and diving drones as well as their mounted sensors.

Fraunhofer FHR is concentrating on the passive radar which is to be incorporated into both the flying and floating drones. While radar usually involves a transmitter on the radar unit emitting an electromagnetic signal and an antenna receiving the echo reflected by the objects, in passive radar, the unit itself does not transmit. Instead, it uses signals from other sources, such as radio or television signals. In the case of Roborder, the system uses signals generated by a network of coastal radars. This coastal radar network is operated by one of the project partners – Italian research institute Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT). Like the passive radar receivers on the drones, it operates in the X-band, i.e. at approximately ten gigahertz.

Increasing the range by up to 20 percent

But what is the need for the passive receivers on the drones if there is already coastal radar? Coastal radars are located on land, so they are relatively far away from vessels that are heading toward the coast – possibly without permission. The coastal radar emits its waves, which are reflected by the vessel and then have to travel all the way back to the on-land radar unit. However, the further they have to travel, the weaker the signals become. The drones, on the other hand, swim or fly back and forth two to three kilometers offshore at a time, parallel to the coastline. The distance that the reflected signals have to cover to reach the antenna is therefore far shorter for the drones than the distance to the antennas on land. According to theoretical calculations by Fraunhofer FHR, this extends the radar's range by up to 20 percent – while maintaining the same probability of detection. The practical demonstration is scheduled for spring 2021. It will be held jointly with the CNIT off the coast of the Italian province of Livorno.

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- Autonomous driving is a major future trend which, starting from the roads, is increasingly spreading to rail and sea transport as well as aviation.
- Radar is the key sensor for more autonomy on road, rail, water and in the air. After all, the safety of all road users must be ensured at all times.
- The Business Unit Traffic offers in-depth and broad-based scientific expertise in all aspects of radar, supplemented by industry knowledge.

RADAR SYSTEMS FOR INCREASED SAFETY IN CARS, ON AIRPLANES, TRAINS AND SHIPS

Cars that autonomously make their way through dense traffic while people comfortably lean back and read the paper – autonomous driving is a huge future trend in the traffic sector. Spurred on by the automotive sector, the trend is increasingly expanding to encompass other modes of transport as well. Whether on the road, on rails, on the water, or in the air: Safety is essential for autonomous driving. The vehicles must be able to observe and assess the traffic around them to initiate the required responses – for instance to fully brake when a child runs onto the street. Radar sensors are ideal for this task: Because, in contrast to optical sensors, they work day and night and in any weather condition – even in dense fog. One could say: Radar is the key sensor for more autonomy on the road, on rails, on the water, and in the air.

When it comes to radar, Fraunhofer FHR's Business Unit Traffic offers deep and diversified expertise: From high frequency systems and signal processing to the classification of objects all the way to electromagnetic simulations. The business unit boasts high-quality cutting-edge technical equipment and a staff with in-depth physical knowledge. But there is more: The staff members are also very well versed in the mobility industry and extremely familiar with current challenges and issues. Thus, in the Business Unit Traffic, even challenging problems can be resolved in a beneficial way and tailored individually to the customer.

On the road...

Nowadays radar sensors are installed in cars as a standard feature to support drivers. The Business Unit Traffic has already contributed its expertise in this area as well: Special radar antennas from Fraunhofer FHR have been installed 30 million times in 100 different vehicle types. Currently, particular focus is on the miniaturization of the systems as well as the development of conformal antennas – meaning antennas that adapt to the car's geometry for an optimal fit into the available constructed space. Further current research approaches in the Business Unit Traffic address the question of how radar waves interact with different materials. This is important, for example, when a radar sensor is to be installed behind a company logo or the bumper, while being invisible to the user. Newly developed sensors are "put through their paces" in a test environment. Our simulation software GOPOSim allows for the insertion of different moving objects such as cars, bikes, pedestrians, and dogs into the different road scenarios.

...on the water, in the air, and on rails

At the moment, the Business Unit is heavily marked by applications in the automotive sector. But the level of autonomy is also increasing in other traffic areas – bringing about the associated requirements for the sensor technologies. For this reason, the Business Unit Traffic has also made significant contributions to the development of a number of radar sensors for shipping and aviation. An example from shipping: The innovative sea rescue system SEERAD makes it possible to locate shipwrecked persons at a distance of six kilometers with a transmission power of only 100 watts – a world record. In the aviation area, Fraunhofer FHR has developed a landing assistance system for helicopters, among others. The system assists the pilot during the landing maneuver, when visibility is reduced by stirred up dust.

As far as the activities in railway traffic are concerned, the goal is to keep developing these in the future – because there are barely any solutions available in the market yet. The Business Unit Traffic wants to close this gap. There are numerous applications for radar systems in railway traffic: For example, the sensors could analyze the track beds, detect cracks in tunnel walls, measure track widths, and address similar questions.

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1 Test measurement at Fraunhofer IIS: A person is detected by the radar before and after setting off, and the determined position is checked via an optically monitored marker on the helmet.
2 MIMO radar sensor developed at Fraunhofer FHR for motion detection.
3 Are any of the people on the road moving?

MORE SAFETY ON THE ROADS

Pedestrians, cyclists, streetcars, cars – traffic can become confusing at times. In the future, a new type of radar sensor system will be able to warn drivers in good time if somebody is steadily approaching their car. It was developed by Fraunhofer Institutes FHR, IIS and IVI. In a follow-up project, the system will be able to interpret entire street scenes via artificial intelligence, thus ensuring even greater safety.

People react quickly – but sometimes not quickly enough. For example, if a child runs across the road to catch a bus that has stopped on the opposite side, a car driver is very unlikely to be expecting this to happen – with potentially extremely serious consequences. Although sensors can detect when people or other objects are close to a vehicle and warn the driver, the warning would come too late in the case of a child running into the road. In the HORIS project, the FHR Fraunhofer Institute in Wachtberg, IIS in Erlangen and the "Connected Mobility and Infrastructure" IVI Application Center in Ingolstadt have set themselves the goal of improving road safety – particularly in situations involving large numbers of road users. Instead of a proximity warning as in the past, reliable behavior prediction is to be realized. This means that if a child runs onto the road, the sensors should detect this at a stage when the driver can still react and bring the car to a halt before an accident happens.

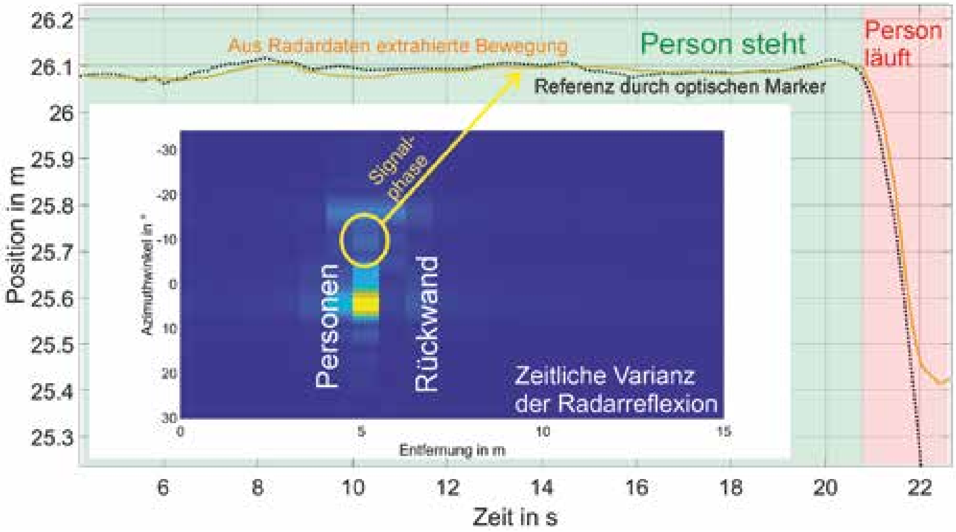
Speed not distance

In doing so, the Fraunhofer research team is building on existing technology from the automotive industry, using both the same radar chip technology and the same components for the sensors. The main development work lies in evaluating the data, i.e. in the algorithms. The highlight: While currently installed sensors analyze how far a person is from the car, the new system relies on measuring the speed. Thus, an imminent danger is detected at the very beginning of a movement, and valuable, sometimes even life-saving time is gained. The algorithms recognize an object as a person, set a marker and determine the speed and direction in which the person is moving. Are they moving toward the radar sensor and, hence, toward the road? There is a fine line between triggering a false alarm and failing to issue a warning in time, but the radar sensor can overcome this problem by taking around a hundred measurements every second. Only when the person is moving consistently towards the road at a certain minimum speed over several measurements is an alarm triggered to warn the driver.

The three institutes have divided the development tasks in accordance with their competencies: Fraunhofer FHR is concentrating on the technological side and is developing the algorithms, while Fraunhofer IVI is designing suitable test scenarios. Meanwhile, Fraunhofer IIS is taking care of the camera technology and motion detection and providing the measurement halls.

Demonstration planned for spring 2021

The project ran from May to December 2020. The demonstrator is ready: It can currently detect up to eight people at the same time and determine whether they are moving toward the road. It will measure a street scene in a test run at the



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beginning of 2021. An overall test and a presentation for interested customers from industry is planned to take place in Ingolstadt in the second quarter of 2021.

However, the collaboration between the three Fraunhofer Institutes is far from over. They plan to build on the HORIS results in a follow-up project which aims to further optimize the sensor, this time not just looking at whether someone is moving toward the road, but also taking account of the issues determining how and why they might make that move. As well as detecting that someone is approaching the car, the system will use artificial intelligence and an additional infrared camera to understand the overall situation. The aim here is to improve the system's reaction time. If, for example, a ball rolls into the road, a child may well follow it a few seconds later. If a bus stops, it is possible that someone will rush across the road to catch it. By detecting the whole situation rather than just the movements of individual people, the system can save valuable extra seconds when warning the driver and help prevent dangerous situations. In addition, the situational awareness feature is designed to increase accuracy and thus further reduce false alarms. And to further increase the safety of all road users in the long term.

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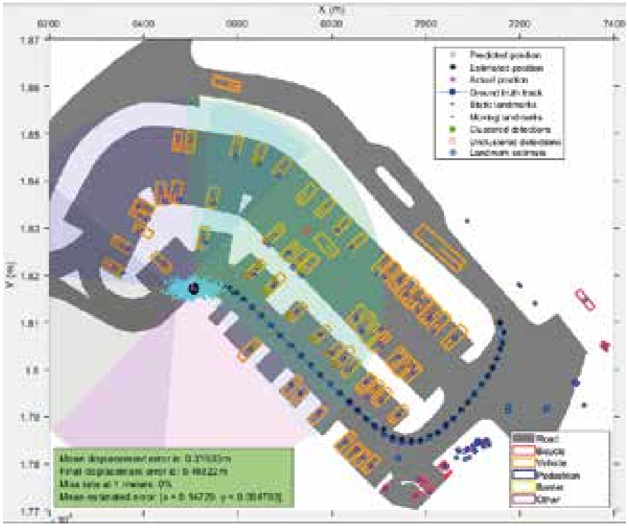
Scenario with ground truth trajectory, estimated trajectory and landmarks.



ACCURATE POSITIONING FOR SELF-DRIVING CARS

Is the car in the correct lane? How far away is the crosswalk? What a human driver usually estimates with a glance it can only be carried out by means of sophisticated sensors in self-driving cars. Fraunhofer FHR has now investigated what radar sensors are able to do in this regard. The result: They can be used to determine the car's position to within a few centimeters.

If cars are to self-drive through roads and streets in the future, this will require a number of basic technologies. Among other tasks, the vehicle must be able to determine its position to within a few centimeters and, if necessary, create a map of its surroundings. This is also known as Simultaneous Localization and Mapping (SLAM) and it is particularly necessary in areas where the GPS signal is not accurate enough or the surroundings are unknown and no map material is available. The environment can usually be measured with three types of sensors: Optical cameras, LiDAR and radar. Optical cameras only work in bright light and with reasonably good visibility. LiDAR systems are bulky and expensive, and their results are not very reliable in poor weather conditions. Radar systems offer an alternative: They provide reliable results even in fog, heavy rain and darkness.

Investigation based on real test data

Can this kind of self-positioning be achieved in a car using radar sensors? This was investigated at Fraunhofer FHR. The utilized test data came from nuScenes, a large-scale public dataset for autonomous driving. This includes both radar and LiDAR data, as well as data from optical cameras. The framework originates from the field of robotics – after all, robots too have to be able to move in their environment without causing accidents, and to do this, they need to record their surroundings in great detail.

Since radar data is too large to evaluate each individual point, data belonging to one object is combined. This process is assisted by boundary frames created using sensor data from the camera and LiDAR. For example, if a bounding box is created for a car, all radar data within that box will be clustered. The work regarding SLAM shows: While self-location techniques that use only radar data and known landmarks allow for higher positioning accuracies, SLAM techniques also permit to simultaneously generate a map with radar data when no other sensor data is available. The position of the car can be determined up to 20-30 centimeters accuracy.

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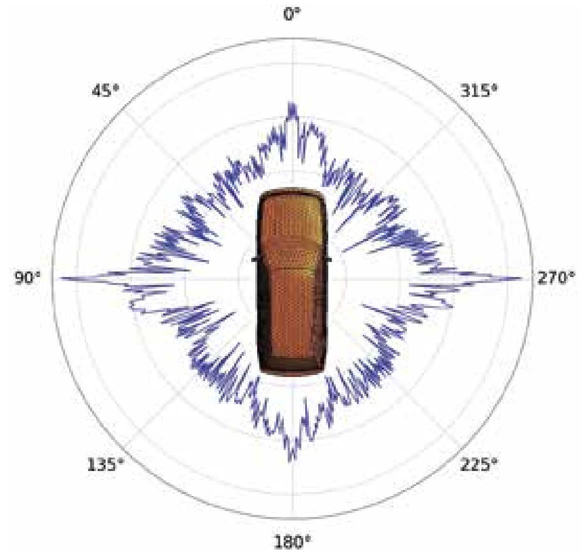

Simulated RCS (Radar Cross Section) of a Golf III model.

TIME-DYNAMIC RADAR SIMULATION OF TRAFFIC SCENARIOS IN REAL TIME

Up to now, developing new driver assistance systems has required numerous test drives. After all, the decision algorithms have to be trained accordingly. Fraunhofer FHR has now developed a simulation tool that generates raw radar data and electromagnetically simulates time-dynamic processes – based on physical optics and, depending on the complexity, in real time. It is therefore ideally suited to replacing time-consuming test drives.

Driver assistance systems make it easier for drivers to maintain an overview and thus ensure greater safety. This requires environmental sensors that reliably "keep an eye" on the car's surroundings, as well as algorithms that evaluate this data and make the necessary decisions with regard to safety. Up to now, these algorithms have mainly been tested and trained on real test drives – a time-consuming and expensive undertaking.

Fast simulations instead of lengthy test drives

Fraunhofer FHR's GOPOSim tool can be used to generate raw data for testing the algorithms – thus replacing test drives. An additional special feature: It can also be used for time-dynamic processes, such as those that occur everywhere in traffic scenarios, for example when a cyclist from a side street crosses the lane without looking. The simulation tool is already being used in various projects with customers from industry. The results can also be processed as an object list and used in the ATRIUM radar target simulator, which can be used to test radar sensors over the air.

The software can be used to create raw data suitable for evaluating micro-Doppler effects on moving objects in the scene. These occur when multiple larger and smaller movements are superimposed onto an object – for example, the movement of the arms and legs of a running pedestrian, where the limbs move independently of the pedestrian themselves. Through appropriate algorithms, such micro-Doppler signatures can be used to carry out classifications that can enable the identification of a pedestrian, cyclist, or a vehicle. The simulation is based on a deterministic ray tracing method as well as physical optics in calculating the scattering on the objects. Unlike the shooting and bouncing rays algorithm, in which a fixed number of rays are sent into space, GOPOSim only emits rays that are known to hit objects into space – this is referred to as an analytical approach. The decisive advantage: The simulation time can be significantly reduced. Plus, depending on the complexity, simulations are already possible in real time. This is a prerequisite for software in the loop or hardware in the loop simulations.

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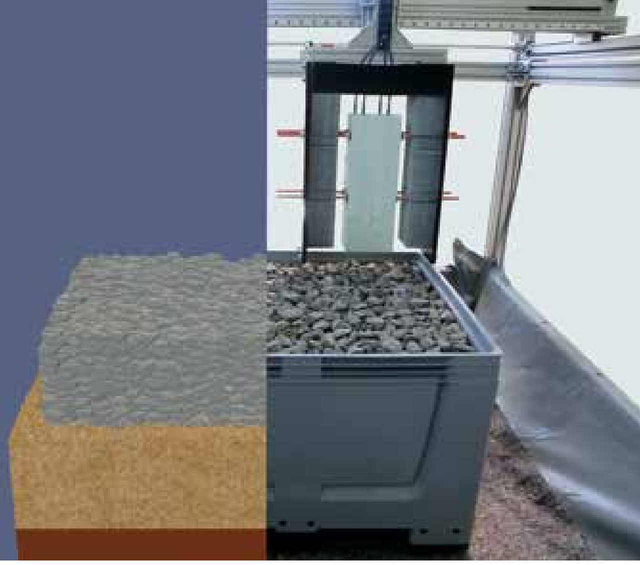

Synthetic model of a track bed (left) next to Experimental model (right) including GPR sensor.

EARLY DETECTION OF TRACK BED DAMAGE USING RADAR

During incessant rains, for example the monsoon, even sophisticated track beds have little chance of draining the water. This results in undercutting and holes, which can in turn lead to serious accidents. Using a ground-penetrating radar system, such undercutting can be detected in good time along the entire length of the track in a contactless process.

Track beds essentially consist of three different layers: The ballast bed, also known as bedding, the subgrade protection layer and the substructure or subgrade. The function of the structures is to distribute the weight of the train evenly over the ground and to allow rainwater to run off. However, the ravages of time gnaw away at the track beds: Some ballast stones crack due to the pressure of the trains, and the track bed also widens and becomes shallower over the years. The main problem is too much rain, for example in monsoon areas, or melt water in mountainous regions: The water can wash out the ballast bed and substructure and tear holes in them, which can in turn lead to serious accidents. However, verifying these signs of wear and tear has hardly been possible up to now. The current possibilities are visual inspection and digging a hole to check the structure at random intervals.

Non-destructive analysis of the entire track bed

Together with RWTH Aachen University, Fraunhofer FHR has now developed a GPR (Ground Penetrating Radar) system that can be used to examine the track beds non-destructively and over their entire length. To do this, the radar system must be mounted on a mobile platform that can travel along the track and examine it. The system can detect holes down to a depth of about one meter, which is more than adequate for a normal track bed depth. The spatial resolution is one centimeter. This enables the acquisition of high-resolution radar images, which can be used to examine small structures within the track ballast.

The main challenge lies in evaluating the collected data: Where in the track bed is there damage? A sophisticated system made up of real-life tests, simulations and machine learning helps with this. In a track bed model, cavities within the track bed were firstly modeled under various conditions such as ballast contamination and aging, then measured using ground penetrating radar. These real-world results were used to improve the simulation model. The simulation results, in turn, created the huge database needed to train the machine learning. Generating this database using trackbed models alone would take several years, whereas simulating the required data requires only a fraction of the time. The simulation model is ready, and one company has already expressed interest.

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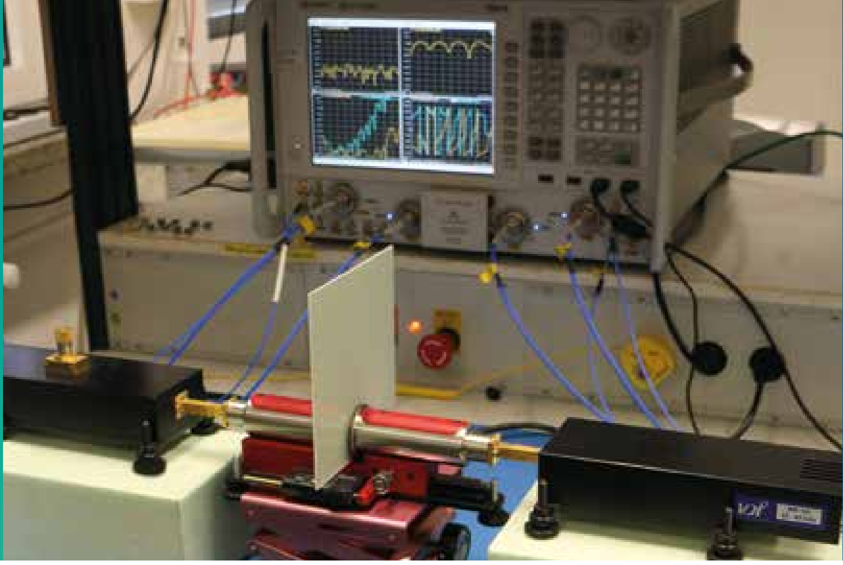

To determine the material parameters, transmission and reflection of nearly plane electromagnetic waves are measured first.

PRECISE MATERIAL CHARACTERIZATION

Vehicles come with numerous in-built sensors that scan the environment and provide valuable data for driving assistance. It is therefore important for vehicle manufacturers to know how the vehicle's parts change the electromagnetic signals that the sensors emit and receive. Fraunhofer FHR carries out such analyses precisely and, in addition to the results, is now calculating information on the measurement accuracy for the first time.

Without a driver, the vehicle meanders through the streets while the occupants stick their noses in books or look at their smartphones – at least that is the long-term vision of autonomous driving. It is essential that the cars are able to recognize their surroundings at all times and correctly assess dangers. This is the task of driver assistance systems, which are being installed in vehicles more and more often. The environment recognition is based on numerous different sensors: Integrated into the car, they detect obstacles on the road and pass on their data to the vehicle control system, which can, for example, initiate a braking maneuver in the event of imminent danger. Radar sensors use electromagnetic waves to perceive their environment. These waves have to propagate not only through the air until they hit a potential obstacle, but also through the car parts behind which the radar is installed. Manufacturers therefore want to know for example: How do the vehicle materials, including the various layers of paint, affect the electromagnetic waves? What is the effect of the various painting processes?

Analyses...

Fraunhofer FHR is carrying out corresponding investigations for numerous customers. The measuring equipment can be used to professionally measure and characterize various material types – even those consisting of several different homogeneous layers. Two electromagnetic parameters are determined for this purpose. One parameter is the dielectric constant, which is an indication of how the material interacts with the electric field of the wave. The second is the loss factor, which describes the attenuation experienced by the wave when it interacts with the material.

...with measurement inaccuracies and standard deviations

Plus, a new point: In the future, besides the measurement results they received before, customers will also receive an indication of the measurement inaccuracies – more precisely, the distribution of the measurement results as well as the standard deviation. This means that they will be able to accurately assess the measurement inaccuracy that is occurring, and the results will be even more concrete and meaningful for them than they were before. They will even be able to combine the different measurements from several laboratories to get the best possible estimate of the parameters of a material and their measurement uncertainties. In addition, Fraunhofer FHR has identified elements in the measurement setup that can be used to further optimize the measurement accuracy in a further step.

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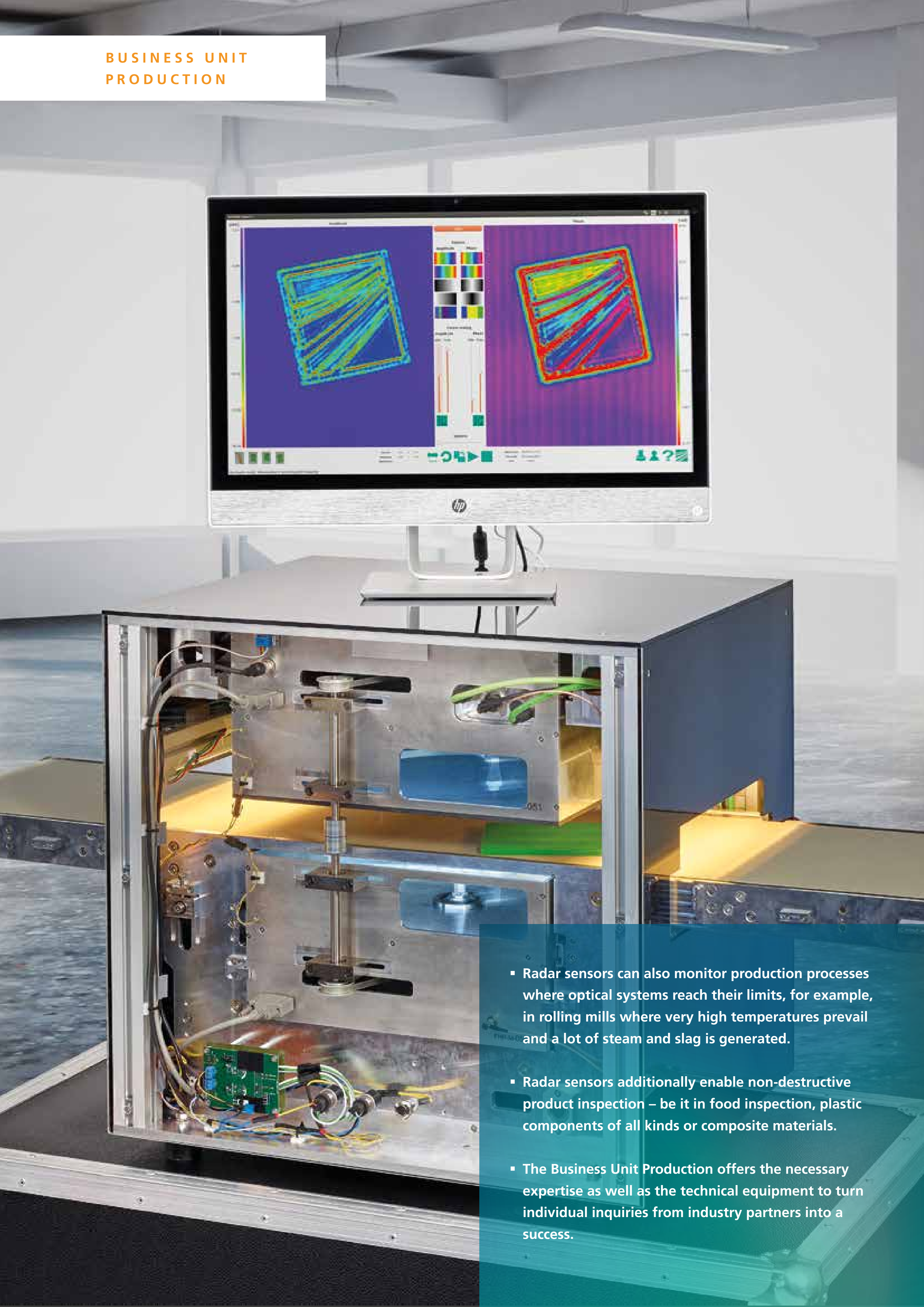

- Radar sensors can also monitor production processes where optical systems reach their limits, for example, in rolling mills where very high temperatures prevail and a lot of steam and slag is generated.
- Radar sensors additionally enable non-destructive product inspection – be it in food inspection, plastic components of all kinds or composite materials.
- The Business Unit Production offers the necessary expertise as well as the technical equipment to turn individual inquiries from industry partners into a success.

PRODUCTION PROCESSES ALWAYS IN VIEW

When something goes wrong in industrial production processes, this will very quickly lead to high costs. Thus, companies have a major interest in monitoring production processes. While some questions can be satisfactorily addressed using camera and laser systems, other production processes require sensors with capacities that go beyond those of optical systems. Radar sensors offer an ideal solution here: They are not only capable of measuring under difficult environmental conditions, for instance with limited visibility, but also of looking through dielectric materials to detect defects. Fraunhofer FHR's Business Unit Production offers the necessary expertise for all questions relating to radar.

Non-destructive testing for food, plastics and composites

Sometimes, it makes sense to not only check the products surface, like for car doors, but to also have a look inside – without destroying the objects. Radar makes this possible as well, at least for dielectric materials. One of the applications is food testing: This involves detecting foreign matter that has accidentally gotten into the food in the production process.

Radar is also a promising solution for non-destructive testing of additively manufactured components, i.e. 3D printed plastics. In addition, radar examinations offer benefits during the lifespan of a product, for instance for composite materials like the ones used for the rotor blades of wind turbines. FHR is developing imaging algorithms for high-resolution millimeter-wave radar scans at 60 GHz for this purpose. One of the areas in which this work is being carried out is the FiberRadar project, funded by the EFRE Leitmarkt-Agentur.NRW. These are used to monitor fiber optic systems in fiber composite production. Promising results have already been achieved here using FHR's broadband radar technology at 80 and 220 GHz. FHR's fully integrated SiGe chip solution at 220 GHz can achieve high image resolution, making both fiber layers and material defects clearly visible. Greater penetration depths can be reached by fusing multiple frequency bands.

Checking production processes for metals

One interesting field of application for radar systems are rolling mills in the steel industry. In general, the following applies to production processes: The earlier defects are detected, the cheaper it is to correct them. For example, if a car door has a dent, it can be easily sorted out in the beginning. But further along the value chain, each additional production step costs hard cash. Panels designated to be made into car doors are also frequently checked visually for defects. A millimeter wave sensor allows for the reliable detection of even the smallest of scratches. In the long run, this could even provide 100 percent control.

Looking to the future: Smart factories and additive manufacturing

What will production look like in the future? One possible vision is the smart factory, where the supply of components and production are run intelligently and autonomously. However, autonomy always starts with the sensors: This is where the Business Unit Production offers the required expertise as well as the capabilities to develop individual solutions for safety-critical aspects such as machine safety.

Additive manufacturing, in which components are produced in 3D printers, is another future trend. For example, this allows antennas to be printed or component concepts to be realized that could not be produced in this way before. Together with high-frequency technology, additive manufacturing opens up numerous new fields of application: For example, the antennas could be integrated directly into functional components of the production machine by making the component function like an antenna at the point where it is penetrated by the radar wave.

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1 *Radar width measurement on the roughing stand of Salzgitter Flachstahl GmbH.*
2 *STRIKE sensor integrated into the IMS thickness gauge.*
3 *Measuring bracket of IMS Messysteme GmbH's thickness measuring system.*

USING RADAR TO CHECK STEEL SHEET THICKNESS

When steel strips are being rolled, they have to be checked to make sure they have the desired thickness. In applications where adverse environmental conditions such as steam, scale and spray water prevail, this has previously only been possible with ionizing isotope or X-ray technology. In contrast, a novel radar system measures the thickness of various materials in the submillimeter range even under adverse conditions – and even without ionizing radiation.

Be it for cars or component cladding, steel is often processed in the form of strips. To this end, the slabs of raw material are rolled out step-by-step into long strips in rolling mills and rolled into coils for transport. An elementary feature of the rolling process is that the strip produced must be of the specified thickness over its entire length, which should not have any major fluctuations. Strip or sheet thickness is currently measured mainly using systems based on isotope and X-ray radiation. However, this adds to the costs; after all, it requires radiation protection measures. Moreover, these systems reach their limits when the material is very thick. Then again, optical systems are sensitive to water vapor and fog.

In collaboration with IMS Messsysteme GmbH, Fraunhofer FHR has therefore developed the first thickness measurement system based on radar sensor technology for hot rolling and heavy plate mills. The advantages: Radar systems require only low transmission power, so no additional safety measures are necessary. Unlike optical systems, they are not sensitive to harsh environmental conditions such as fog, spray water and dust. At the same time, radar systems require hardly any maintenance. The electronics are maintenance-free; only the sensor's viewing window must be kept free from dirt, scale and rolling emulsion.

The STRIKE sensor delivers reliable results even under adverse environmental conditions

The Strike sensor developed at Fraunhofer FHR has already been integrated into a thickness measurement system at IMS. Environments where there is vapor, mist and dust and which are aggressive allows the material thickness to be measured reliably and accurately. The measuring system consists of two four-channel radar sensors mounted opposite each other in a C-frame. The two sensors emit radar beams that are reflected by the material passing through and received again by the sensor. Since this happens simultaneously from below and above, the distance values can be calculated from reference calibration data, which allows the strip's thickness to be determined. One challenge is that the steel strip is constantly moving under the sensors at a speed of up to 20 km/h. This must be matched by the measurement rate and the measurements on the top and bottom must be synchronous – this is the only way to achieve highly accurate material thickness measurements continuously. The developed STRIKE sensor ensures this: It currently operates at a measurement rate of one kilohertz. The entire measuring system thus delivers eight times 1000 synchronously recorded distance measurement values per second.

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The evaluation unit is based on FPGAs (Field-programmable Gate Arrays). It is integrated directly into the sensor and allows fully edge-supported evaluation. The entire signal processing of the radar signals takes place on the FPGA – even the control of the radar chips and the communication with IMS Messsysteme GmbH's central computing unit was implemented in this integrated logic unit. Thus, the thickness of the steel sheet can be measured in real time at a rate of one kilohertz.

The accuracy of the thickness measurement is below 100 micrometers for a flat running strip. If the strip surface is inclined, for example due to the strip movement or corrugation, the angular deflections are determined and corrected by means of the quad arrangement. The accuracy of the thickness measurement can thus be kept below +-150µm. With the antenna geometry used, the measurement range of the strip's possible angular positions is up to 3 degrees in each direction.

The sensor is ready. It is currently in the test phase so as to guarantee reliability. Once this is completed, IMS Messsysteme GmbH will integrate the sensors into its setup and deliver its first measuring system to a U.S. rolling mill. Of course, the sensor's application is by no means limited to rolling mills. Indeed, it can be used wherever there is a need to determine distances and angles.

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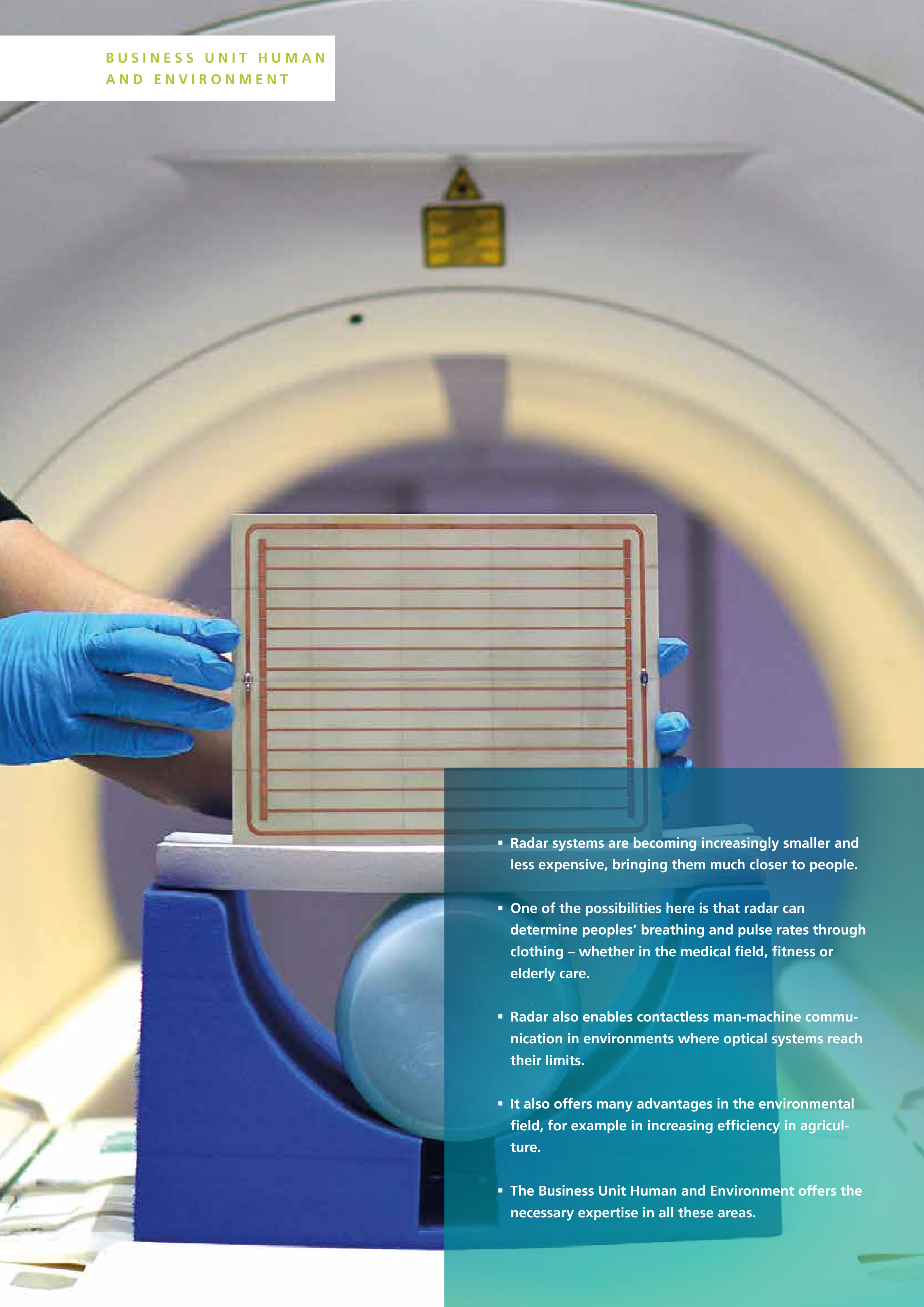

- Radar systems are becoming increasingly smaller and less expensive, bringing them much closer to people.
- One of the possibilities here is that radar can determine peoples' breathing and pulse rates through clothing – whether in the medical field, fitness or elderly care.
- Radar also enables contactless man-machine communication in environments where optical systems reach their limits.
- It also offers many advantages in the environmental field, for example in increasing efficiency in agriculture.
- The Business Unit Human and Environment offers the necessary expertise in all these areas.

RADAR: FOR HUMAN AND ENVIRONMENT

Radar technology is becoming ever smaller and cheaper – now reaching a degree of miniaturization that brings it closer to humans. But where does it make sense to the use of radar in relation to humans? Generally, everywhere where geometric and kinematic values are measured, i.e. where the shape and the movement of an object are to be analyzed.

Radar for humans

One example is checking the vital signs, i.e. breathing and the pulse rate. In this case, radar is used to measure the movement of the chest to conclude the breathing rate, while the pulse rate is deducted from the movement of the skin – and similar to the scanners at the airport, this can be done through the clothing. One area where this is useful is for newborns in hospitals. Further applications are possible in the areas of care for the elderly, sleep laboratories, or even fitness. As far as the signal processing is concerned, a lot of research work is still required in this attractive field. As one of Europe's leading radar institute, Fraunhofer FHR is optimally positioned for these challenges.

Radar is also well-suited for other questions involving man, such as movement analysis, be it for gait analysis in sports or in rehab. For example, together with partners, the staff in the Business Unit Human and Environment conduct research on the question of how relieving postures can be detected after an accident.

Radar for communications

It is not only in the medical environment where radar has a lot to offer, but also in the area of communications. One field of interest is human-machine interaction. For example, many new generation smartphones are already equipped with an integrated radar sensor. The advantage: The sensor recognizes gestures even through clothing. Thus, a user can answer a call with a gesture without having to take the phone out of her jacket pocket. Gesture recognition via radar also makes sense in the area of occupational safety. Thus, you no longer need to press small buttons with thick work gloves and can instead control the machines with gestures and hand signals. This especially makes sense in areas where textile-penetrating gestures are appropriate or where the working environment contains a lot of vapor and steam, for example. The Business Unit Human and Environment is optimally positioned with its expertise to respond to this trend and to provide companies with customized support.

Radar for the environment

The term precision farming refers to increasing the efficiency in agriculture using modern technology. Radar sensors are an ideal fit for this task: It is harmless for people, animals, and plants and can provide not only images of leaves and stems, but also the possibility of examining roots, thus enabling plant-penetrating analyses. In addition, animals are also coming into focus: the detection of wild animals and the vital parameter monitoring of stable animals is another exciting field in which radar technology can open up new possibilities.

In the course of climate change, the importance of weather radar and the weather forecasts bases on it is increasing as well. While these are established technologies, there is still a lot of need for improvement. Here too, the Business Unit Human and Environment is pursing many ideas – because the technological advances that were achieved in the field of radar can also be used for weather radar.

The environment area also includes a flashing red warning light fitted to wind turbines to warn aircraft pilots. In many regions, however, aircraft are the exception. The ParaSol radar developed in the Business Unit Human and Environment recognizes approaching aircraft, allowing the flashing light to be turned on only when needed. The system has already been approved by German Air Traffic Control.

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1 Sample MRI images showing a homogeneous phantom (right) and a kiwi (left) with and without metamaterial plate. The signal-to-noise ratio (SNR) in the marked area (ROI) is indicated in each case. For the phantom measurements (with TR=100 ms), the slice shown is oriented perpendicular to the metamaterial plate, whereas for the measurement with the Kiwi (TR=1 s), the slice is parallel to it.
2 The smart metamaterial plate (manufactured at Fraunhofer FHR) in use in the MR scanner at Fraunhofer MEVIS.
3 The innovative sheath current barrier allows the use of other diagnostic tools under the extreme conditions in the MRI.

METAMATERIALS OPTIMIZE MAGNETIC RESONANCE IMAGING

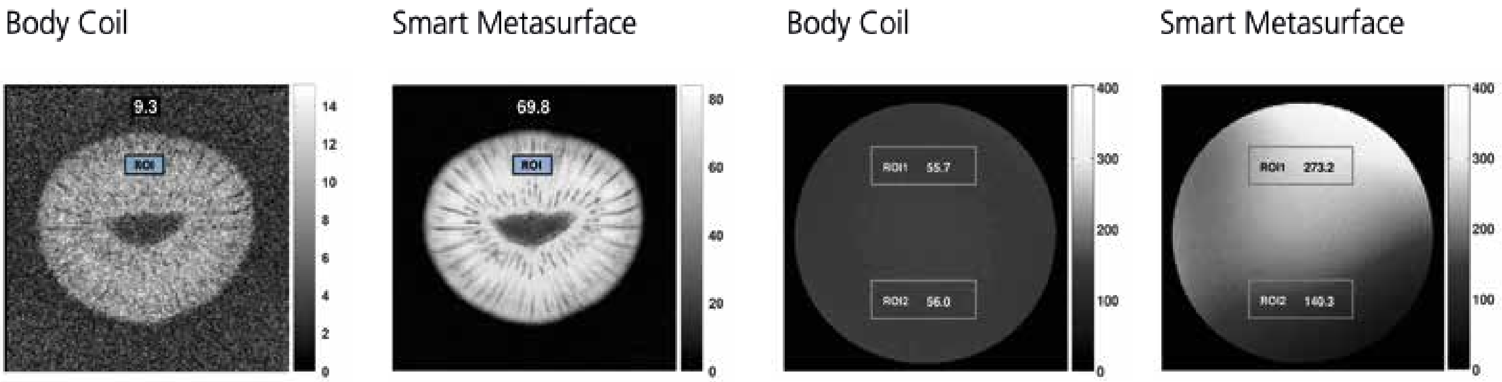
Magnetic Resonance Imaging (MRI) has to date been difficult to combine with other diagnostic methods. This is because the strong high-frequency fields in MRI induce sheath currents on the cables of added devices. Now, MRI-compatible, compact sheath current suppressors based on metamaterial technology from Fraunhofer FHR significantly simplify this. Furthermore, smart metamaterial plates result in a far higher signal-to-noise ratio in MRI: The detection of fine structures is significantly enhanced.

MRI has become an indispensable part of medical diagnostics. Among other things, it allows the brain and spinal cord, as well as internal organs, muscles and joints to be imaged layer by layer and examined non-invasively. But sometimes making a correct diagnosis is not enough – a combination of different diagnostic procedures is required. However, this presents challenges: The MRI's strong high-frequency fields induced into the cables of additional devices, be they ultrasound equipment, monitors or similar devices, can interfere with the measurements. Heat can also be generated at the cables' shields by the induced currents to the point that they can cause burns in patients. Therefore, it is essential to suppress the induced sheath currents. This is typically done using current chokes. These are based on winding up the leads in order to realize the highest possible impedance for the sheath currents. However, this approach is too bulky and requires more space and long leads. Other solutions are based on ferrite beads that can be attached to the respective cable by means, e.g. of a snap lock. Nevertheless, due to the magnetic nature of such components, they are not suitable for use in MRI.

Sheath current suppressors for MRI

Together with the Fraunhofer Institute for Digital Medicine MEVIS, Fraunhofer FHR has now developed a convenient and practical solution to this problem in an internal project. Either sheath current suppressors are attached only at some points of the cable, or the entire cable is covered with a mantle formed by a multitude of sheath current suppressors. The technology, which is currently being patented, is based on metamaterial technology. These are not materials in the usual sense, but artificial entities that have been given a special structure and behavior. Since MRI scanners operate at various frequencies depending on the design and manufacturer, various sheath current suppressors designs have been developed: For 1.5, 3 and 7 Tesla devices. The sheath current suppressors are compact, tunable and reusable. They also preserve the cable's flexible properties. They can be detached from one cable and attached to another. Furthermore, the cables can be equipped with several different sheath current suppressors at the same time allowing for multiple frequencies and broad bandwidth use. For example, a sheath current suppressor solution for 1.5, 3 as well as for 7 Tesla can be attached to the same cable.

Various sheath current barriers have already been characterized in Fraunhofer MEVIS' research MRI scanner and their functionality has been successfully proven. Fraunhofer FHR also has at its disposal appropriate on-bench measurement equipment, including two coils with which the sheath currents can be specifically generated and measured. Up to now, the sheath



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current barriers have been manufactured using conventional production methods. However, new manufacturing technologies are now being used such as 3D printing technology, i.e. additive manufacturing, which is also possible at Fraunhofer FHR. This provides a cost-effective and at the same time high-performance solution.

Metamaterials improve measurement sensitivity by a factor of five

Metamaterial devices also offer many advantages and opportunities in improving MRI images themselves. Among other things, they can significantly improve measurement efficiency: If the scan is carried out using surface coils placed close to the patient's body, the signal-to-noise ratio (SNR) can be improved by up to 20 percent, depending on the region to be imaged. If the coils permanently installed in the MRI scanner, the so-called body coils, are used, the SNR can be increased as much as fivefold. Fine structures are thus much more easily-identifiable on the images as the contrast increases considerably. This great leap in measurement efficiency is enabled by smart metamaterial plates, which are placed on the part of the body to be examined during the MRI scan. Various metasurface plates have already been tested in the Fraunhofer MEVIS MRI research lab and their enhancing effect has been successfully demonstrated.

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Monitoring system for the contactless recording of vital parameters.

COVID PATIENTS' CONDITION ALWAYS IN VIEW

Only a small proportion of covid patients are in intensive care. For all of them, however, the question arises: Is their condition deteriorating? A sensor system being developed by various Fraunhofer institutes in the M3-Infekt consortium project is designed to detect such a deterioration at an early stage – using, among other things, a MIMO radar that analyzes the breathing rate without contact.

Is the covid patient's condition deteriorating? This question arises not only in intensive care units, where they are monitored very closely, but also in other hospital wards and in home care. A modular, multi-modal and mobile sensor system called M3-Infekt will in the future be able to keep a constant eye on the condition of those infected and detect deterioration at an early stage. Fraunhofer FHR is part of a consortium consisting of 10 Fraunhofer institutes. In the future, the developed sensor system will not only monitor the health status of COVID-19 patients, but will also be used in those infected by other infectious diseases.

Different sensors work together

The sensor system consists of different sensor groups that complement each other. Wearable sensors that can be worn on the body constitute one of these groups. A textile-integrated sensor records ECG data, a sensor wristband records body temperature, pulse and blood oxygen saturation, and another textile sensor records the ventilation situation of the lungs. Also part of the project is energy harvesting, where concepts and solutions are being developed on how these wearable sensors can be powered by mechanical movement.

MIMO radar sensor measures breathing rate

Fraunhofer FHR is contributing a contactless MIMO radar sensor. This can be installed in the corner of a room, for example. From here, it determines the breathing frequencies of the people who are in the sensor's wide field of view. The chest movements caused by breathing can be detected by radar even through bed covers. The sensor design used here allows signals from different people to be isolated. If a patient's basic breathing rate changes, this can be an indication of a deteriorating condition. In addition to the radar sensor, there is another non-contact sensor: A hyperspectral image sensor from Fraunhofer IIS/ENAS. Its results can help factor out multiple reflections and the resulting ghost targets of the MIMO radar. The sensors should be built up to the point where they can be used for initial subject studies by mid-September 2021.

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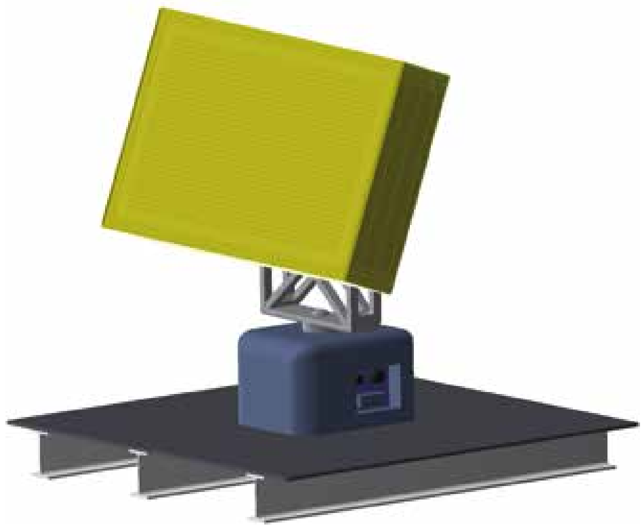

Concept rendering model, front.

SHORT-RANGE WEATHER RADARS FOR OPTIMIZED FORECASTING

Currently, weather forecasts are mostly based on long-range radars. However, long-range weather sensing brings intrinsic limitations: Due to the curvature of the Earth, about 70% of the troposphere below one kilometer cannot be observed, and the temporal and spatial resolutions are also quite coarse. Conversely, short-range weather radars in development at Fraunhofer FHR can potentially sense the lower troposphere and dramatically improve spatial and temporal resolutions.

Rain, hail, storms, sunshine: The weather is part of our lives. Although the forecasts in Germany are generally good, there are often heavy rain events, flash floods or storms that hit entire regions completely unprepared. In addition, many countries in the World cannot afford reliable and localized weather forecasting.

Weather monitoring is usually based on mechanically rotating long-range weather radars covering a range of about 250 kilometers. The emitted radar beams directed at lower altitudes bend only moderately towards the Earth's surface. Therefore, a widening gap to the surface quickly develops as the distance from the sensor increases. For this reason, nowadays, about 70 % of the troposphere below one kilometer cannot be observed by radar means. Moreover, long-range radars demand for high ownership costs, around several millions Euro, and require about five minutes to complete a volumetric sampling of the hemisphere, a time interval often too coarse to timely capture important weather events.

Better temporal and spatial resolution

A network of micro-radars could overcome these disadvantages and improve the accuracy of weather forecasts. At the comparatively shorter range of 50 kilometers, the curvature of the Earth plays a negligible role, finally allowing full sensing of the lower troposphere. Moreover, electronic beam steering in elevation enables much faster sounding of the hemisphere. Indeed, a volumetric scan by electronic means only takes one minute, thereby improving the temporal resolution respect to long-range radars by a factor five. Fraunhofer FHR is being developing such technology demonstrator within a weather radar initiative aiming at advancing radar meteorology in Central Europe. To this end, a Memorandum of Understanding has been signed and finalized with the Meteorological Institute of the Rheinische Friedrich-Wilhelms University in Bonn and the Delft University of Technology in the Netherlands.

A flat-panel micro weather radar is prospected to be installed on the roof of Fraunhofer FHR in Villip and deliver initial results by the end of 2021. Plans for industrialization of the prototype together with the German and European industry are under evaluation. To this respect, one key condition is well kept on the foreground: The system should be commercialized at a comparatively inexpensive price point around 100 K€, finally opening new possibilities for next-generation weather sensing.

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EDUCATION AND TRAINING

Lectures

WS 2019/2020

Bertuch, Thomas: "Antennen und Ausbreitung", Fachhochschule Aachen

Brüggenwirth, Stefan: "Kognitive Sensorik", Ruhr-Universität Bochum

Cerutti-Maori, Delphine: "Radar Systems and Measurements", Technische Universität Braunschweig

Cerutti-Maori, Delphine: "Signal Processing for Radar and Imaging Radar", Rheinisch-Westfälische Technische Hochschule Aachen

Heberling, Dirk: "High Frequency Technology - Passive RF Components", Rheinisch-Westfälische Technische Hochschule Aachen

Heberling, Dirk: "Hochfrequenztechnisches Praktikum", Rheinisch-Westfälische Technische Hochschule Aachen

Heberling, Dirk: "Moderne Kommunikationstechnik - EMV für Mensch und Gerät", Rheinisch-Westfälische Technische Hochschule Aachen

Knott, Peter: "Antenna Design for Radar Systems (VO)", Rheinisch-Westfälische Technische Hochschule Aachen

Knott, Peter: "Antenna Design for Radar Systems (UE)", Rheinisch-Westfälische Technische Hochschule Aachen

Krebs, Christian: "Leiterplattendesign", Hochschule Koblenz

Pohl, Nils: "Bachelor-Vertiefungspraktikum Elektronik", Ruhr-Universität Bochum

Pohl, Nils: "Elektronik 1 - Bauelemente", Ruhr-Universität Bochum

Pohl, Nils: "Grundlagenpraktikum ETIT", Ruhr-Universität Bochum

Pohl, Nils: "Integrierte Hochfrequenzschaltungen für die Mess- und Kommunikationstechnik", Ruhr-Universität Bochum

Pohl, Nils: "Master-Praktikum Schaltungsdesign integrierter Hochfrequenzschaltungen mit CADENCE", Ruhr-Universität Bochum

SS 2020

Brüggenwirth, Stefan: "Grundlagen der Radartechnik", Universität der Bundeswehr München

Caris, Michael: "Radar in der Medizintechnik", Hochschule Koblenz

Ender, Joachim: "Radar - Techniques and Signal Processing", Universität Siegen

Heberling, Dirk: "Elektromagnetische Felder in IK (ehemals EMF 2 IK)", Rheinisch-Westfälische Technische Hochschule Aachen

Heberling, Dirk: "High Frequency Technology - Antennas and Wave Propagation", Rheinisch-Westfälische Technische Hochschule Aachen

Heberling, Dirk: "Hochfrequenztechnisches Praktikum", Rheinisch-Westfälische Technische Hochschule Aachen

Knott, Peter: "Radar Systems Design and Applications", Rheinisch-Westfälische Technische Hochschule Aachen

Krebs, Christian: "Leiterplattendesign", Hochschule Koblenz

Pohl, Nils: "Master-Praktikum Schaltungsdesign integrierter Hochfrequenzschaltungen mit CADENCE", Ruhr-Universität Bochum

Pohl, Nils: "Integrierte Digitalschaltungen", Ruhr-Universität Bochum

Stanko, Stephan: "Radar in der Medizintechnik", Hochschule Koblenz

Supervised doctoral studies

Giovanneschi, Fabio: "Online dictionary learning for classification of antipersonnel landmines using ground penetrating radar", Universität Siegen

Krämer, Patrick: "Studies of Higher Order Mode Couplers for the Upgraded Travelling Wave Acceleration System in the CERN SPS", Rheinisch-Westfälische Technische Hochschule Aachen

Marquardt, Pascal: "Adaptive Spectral Least-Square Techniques for Reaction-Diffusion Equations", Universität Duisburg-Essen

Wasserzier, Christoph: "Noise Radar on Moving Platforms", Tor Vergata University of Rome, Italien

Supervised master theses

Arumugam, Ram Kishore: "Development of super-resolution detection algorithms for sparse scenes in presence of clutter", Technische Hochschule Ingolstadt

Awadhiya, Rajat: "Increasing the coherent integration time for space surveillance radar operations", Rheinisch-Westfälische Technische Hochschule Aachen

Bauer, Alexander: "Micro-Doppler Based Limb Detection For Gait Analysis", Hochschule Koblenz

Cetin, Zuhal: "Design und Realisierung eines D-Band Verstärkers in einer SiGe-BiCMOS Technologie", Ruhr-Universität Bochum

Esser, Niclas Alexander: "Konzeptionierung und Programmierung eines Systems zur echtzeitfähigen Datenaufzeichnung, Verarbeitung und Visualisierung von Radarsignalen", Hochschule Bonn-Rhein-Sieg

Galleguillos Loza, Pablo Ernesto: "Vitalparametermessung bei Nutztieren mithilfe eines zweikanaligen 94GHz FMCW-Radars", Hochschule Bonn-Rhein-Sieg

Jung, Marie: "Kontaktlose Blutdruckmessung mithilfe eines CW-Radars anhand von Modellen des maschinellen Lernens", Hochschule Trier

Langmesser, Florian: "Design and Implementation of a Low-Power Narrow-Band Radar Transmitter at X-Band", Fachhochschule Aachen

Liebelt, Lukas: "Entwicklung eines synchronisierbaren, kohärenten Frequenzkonverters auf Basis der direkten digitalen Synthese", Technische Hochschule Bingen

Nalkay, Rahul: "Design of a carrier platform and Analysis of a Cooling High-Power Transmit Modules of a Radar", Ernst-Abbe-Hochschule Jena

Chaudhury, Nandan Dutta: "An investigation on the possibility for bandwidth improvement of dielectric antennas via modification of their geometry", KTH Royal Institute of Technology, Schweden

Oevuenc Kaya, Sertac: "Baseband Receiver Opimization for NR mmWave Mobile Radio Testing", Rheinisch-Westfälische Technische Hochschule Aachen

Ramesh, Avinash Nittur: "SLAM with RADAR in Automotive Applications", Universität Siegen

Schneider, Moritz: "Development and Construction of the Mechanics for a 16-Element Phased-Array Radar to Analyse Fragmenting Objects in Earth Orbit", Rheinisch-Westfälische Technische Hochschule Aachen

Schneuing, Arne: "Reconstruction of Undersampled Magnetic Resonance Fingerprinting Data", Rheinisch-Westfälische Technische Hochschule Aachen

Schuth, Kim-Simon: "Entwurf und Implementierung einer Automatisierungssoftware für das MIRANDA 300 Radarsystem", Hochschule Koblenz

Slavov, Angel: "Implementation of an FM-based multistatic passive radar using a software defined radio", Rheinisch-Westfälische Technische Hochschule Aachen

Smarza, Sonja: "Design und Realisierung eines Frequenzteilers in einer SiGe-BBiCMOS Technologie", Ruhr-Universität Bochum
Spenrath, Tobias: "Development of an Adaptive Zero-IF Receiver for Narrow-Band Radar Applications at X-Band", Fachhochschule Aachen

Spenrath, Florian: "Development of an Adaptive Zero-IF Receiver for Narrow-Band Radar Applications at X-Band", Fachhochschule Aachen

Thindlu Rudrappa, Manjunath: "Vitalparameterdetektion bewegter Personen mit MIMO-Radar", Rheinisch-Westfälische Technische Hochschule Aachen

Ugurmann, Glen: "Entwurf eines Spannungsreglers für einen RFID-Transponder in einer 65nm CMOS Technologie", Ruhr-Universität Bochum

Valdes Crespi, Ferran: "Implementation of a distributed time and frequency synchronisation system based on two way time transfer", Rheinisch-Westfälische Technische Hochschule Aachen

Wallrath, Patrick: "Verfahren zur Bestimmung der Eigenbewegung eines MIMO-Radars unter Verwendung der ZF-Signale und Sensordatenfusion mit einer IMU", Hochschule Trier

Zentarra, Michael: "Untersuchung der Auswirkungen der Strahlschwenkung von 5G", Rheinisch-Westfälische Technische Hochschule Aachen

PUBLICATIONS

To ensure that you have an up-to-date overview of our numerous publications in scientific journals and conferences, all of our publications are available with immediate effect on our website.

All publications 2020:
www.fhr.fraunhofer.de/publikationen2020

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COMMITTEE ACTIVITIES

Behrendt, D.
- Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGZfP): Mitglied

Bertuch, T.
- IEEE Antennas and Propagation Standards WG P145: Mitglied

Brüggenwirth, S.
- IEEE AESS Germany Chapter: Secretary
- EDA Radar Captech: German Governmental Expert
- European Microwave Week (EuMW) 2020: Technical Review Committee
- IEEE Radar Conference 2020: TPC member

Cerutti-Maori, D.
- Inter-Agency Space Debris Coordination Committee (IADC): Nationale Vertreterin in der Working Group 1 (Measurements)
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

Cristallini, D.
- NATO STO Group SET-242 "PCL on Mobile Platforms": Co-Chair
- European Defence Agency: CapTech Member
- European Microwave Week (EuMW) 2020, online: Technical Program Member
- International Radar Symposium (IRS) 2020, online: Technical Program Member
- AGERS 2020, online: Technical Program Member

Danklmayer, A.
- U.R.S.I. International Union of Radio Science, Commission-F Wave Propagation and Remote Sensing: Member
- VDE-ITG Fachausschuss 7.5 Wellenausbreitung: Mitglied
- Deutsche Gesellschaft für Ortung und Navigation (DGON): Mitglied im Fachausschuss Radartechnik
- Radar Symposium (IRS) 2020 Warsaw, Technical Program Committee

Heberling, D.
- European Conference on Antennas and Propagation (EuCAP) 2021, Düsseldorf: Mitorganisator, Mitglied des Steering Committee
- Zentrum für Sensorsysteme (ZESS) 2020, Siegen: Wissenschaftlicher Beirat
- Deutsche Forschungsgesellschaft (DFG): Fachkollegiat
- IMA (Institut für Mikrowellen- und Antennentechnik e. V.): Vorsitzender
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

Klare, J.
- International Radar Symposium IRS 2020, Technical Program Committee
- European Microwave Week (EuMW) 2020, Technical Review Committee
- 7th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI) 2020, Technical Program Committee
- 13th European Conference on Synthetic Aperture Radar EUSAR 2020, Technical Program Committee
- ICP 2020 IEEE 8th International Conference on Photonics, Technical Program Committee

Knott, P.
- Informationstechnische Gesellschaft (ITG) im VDE, Fachausschuss HF 4 "Ortung": Vorsitzender
- Deutsche Gesellschaft für Ortung und Navigation (DGON): Mitglied im Wissenschaftlichen Beirat, Vorsitzender Fachausschuss Radartechnik
- European Association on Antennas and Propagation (EurAAP): Gewählter Regional Delegate
- NATO Research and Technology Organisation (RTO): "Member at Large" des Sensors and Electronics Technology Panels
- Chair of the 20th International Radar Symposium (IRS), Warsaw
- European Liaison for IEEE Radar Conference (RadarCon), Florence

Matthes, D.
- NATO STO Group SCI-332 "RF-based Electronic Attack to Modern Radar": Chairman
- International Radar Symposium (IRS) 2020: Technical Program Committee

Nüßler, D.

- VDI/VDE-GMA FA 8.17 Terahertz-Systeme: Mitglied
- European Machine Vision Association (EMVA): Mitglied
- International Radar Symposium (IRS) 2020, Ulm: Technical Program Committee

O'Hagan, D.

- NATO STO Group SET-268 "Bi-/Multi-static radar performance evaluation under synchronized
- conditions": Chairman
- IEEE AES Magazine: Deputy Editor-in-Chief
- IEEE AES Magazine: Associate Editor for Radar
- IEEE Radar Conference 2020: Special Sessions Co-Chair
- European Defence Agency: CapTech Member
- International Radar Symposium (IRS) 2020: Technical Program Member

Pohl, N.

- International Microwave Symposium (IMS 2020), Los Angeles (online): Technical Program and Review Committee
- European Microwave Week (EuMW) 2020, Utrecht (online): Technical Review Committee
- IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS 2020), Monterey (online): Technical Program Committee, Co-Chair for MM-Wave & THz ICs
- VDI ITG Fachausschuss 7.3 Mikrowellentechnik: Mitglied
- IEEE MTT Technical Committee MTT-24 Microwave/mm-wave Radar, Sensing, and Array Systems: vice-chair
- IMA (Institut für Mikrowellen- und Antennentechnik e. V.): Mitglied
- IEEE (Institute of Electrical Electronics Engineers): Senior Member

Uschkerat, U.

- EDA CapTech Radar: German Governmental Expert
- BMVI Nationalen Vorbereitungsgruppe zur WRC-23 (NVG23): Mitglied
- ETSI TGUWB: Mitglied

Walterscheid, I.

- IGARSS 2020: Scientific Committee
- IEEE Radar Conference 2020: Technical Program Committee
- IEEE (Institute of Electrical Electronics Engineers): Senior Member
- VDE (ITG) Member

Wasserzier, C.

- NATO STO Group SET-287 "Characterization of Noise Radar": Chair
- IRS 2020 TP committee member
- IEEE Sensor Signal Processing for Defense (SSPD) TP committee member

Weinmann, F.

- ITG-Fachausschuss 7.1 "Antennen": Mitglied
- European Conference on Antennas and Propagation (EuCAP) 2020: Technical Review Committee
- IEEE Antennas and Propagation Standards WG P2816: Mitglied
- EurAAP Working Group "Active Array Antennas" (WGA3): Mitglied

Weiß, M.

- EUSAR 2020/21, Leipzig/online: Technical Chair, EUSAR Executive
- IGARSS 2020, Waikoloa: Technical Program Member
- European Radar Conference (EuRAD) 2020, Utrecht: Technical Program Member
- International Radar Symposium (IRS) 2020, Warsaw: Technical Program Member
- Signal Processing Workshop (SPW) 2020, Vilnius: Technical Program Member

Worms, J.

- IEEE Radar Conference: Technical Program Member

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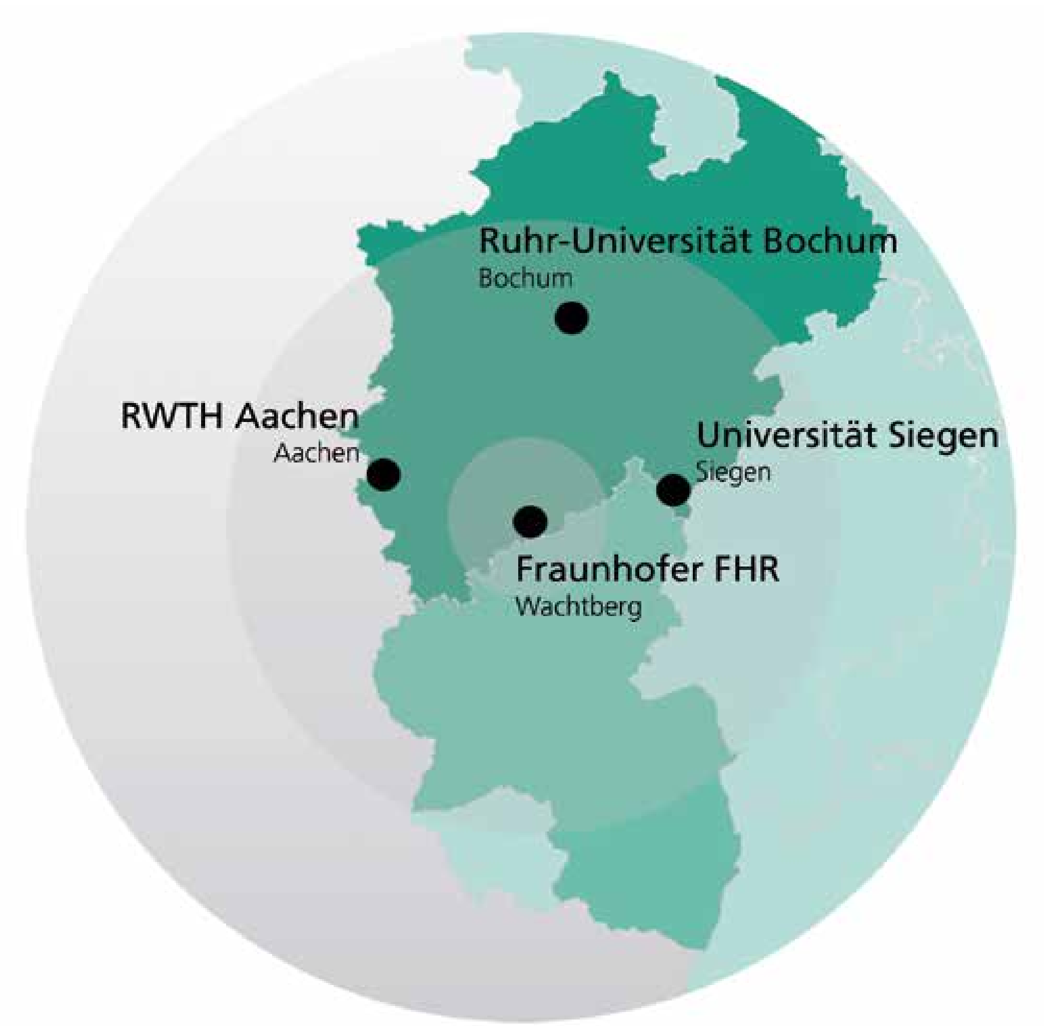

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Title: Fraunhofer FHR / Jens Fiege
P. 2: Fraunhofer FHR / Uwe Bellhäuser
P. 6 Image 1: Fraunhofer FHR, Image 2: Fraunhofer FHR / Bellhäuser, Image 3: Fraunhofer FHR / Fiege, Image 4: Fraunhofer FHR / Wojaczek, Image 8: Fraunhofer FHR / Knott, Image 9: Fraunhofer FHR / Herzer, Image 10: Fraunhofer FHR / Fiege
P. 7 Image 5: Fraunhofer FHR / Welsch, Image 6: Fraunhofer FHR / Fiege, Bid 7: Fraunhofer FHR / Fiege, Image 11: Fraunhofer FHR / Fiege, Image 12: Fraunhofer FHR / Manjunah Thindlu Rudrappa, Image 14: Fraunhofer FHR / Fiege, Image 15: Fraunhofer FHR / Jens Fiege
P. 8: Fraunhofer FHR / Jens Fiege
P. 9: Fraunhofer FHR / Jens Fiege
P. 10 Image 1 / Image 4: Fraunhofer FHR / Carola Welsch, Image 2 / Image 3 / Image 5: DLR / Evi Blink
P. 11 Image 1: Fraunhofer FHR / Jens Fiege, Image 2: DLR / Evi Blink
P. 13: Fraunhofer FHR / Marco Gallasch
P. 17: Fraunhofer FHR / Jens Fiege
P. 22: Fraunhofer FHR / Jens Fiege
P. 25: Image 1 Fraunhofer FHR / Shoykhetbrod, Image 2 Fraunhofer FHR / Uwe Bellhäuser
P. 26: Fraunhofer FHR
P. 29: Image 1 / Image 3 Fraunhofer FHR, Image 2 Fraunhofer FHR / Mies
P. 31: Fraunhofer FHR
P. 32: Fraunhofer FHR / Simon Wagner
P. 33: Fraunhofer FHR / Matthias Weiß
P. 34: Fraunhofer FHR / Andreas Schoeps
P. 36: Fraunhofer FHR / Andreas Schoeps
P. 37: Fraunhofer FHR / Rudolf Hoffmann
S. 38: Fraunhofer FHR / Jens Fiege
P. 39: Fraunhofer FHR / Andreas Fröhlich
P. 41 Image 1: Fraunhofer FHR / Uwe Bellhäuser, Image 2: NASA, Image 3: Shutterstock
P. 42: Fraunhofer FHR / Uwe Bellhäuser
P. 44: Fraunhofer FHR / Carola Welsch
P. 45: Fraunhofer FHR / Diego Cristallini
P. 46: iStockphoto
P. 49 Image 1: Fraunhofer FHR / Reinhold Herschel, Image 2: Fraunhofer FHR / Alexander Shoykhetbrod, Image 3: Fraunhofer FHR / Shutterstock
P. 50: Fraunhofer FHR
P. 51: Fraunhofer FHR / Stefan Wald
P. 52: Fraunhofer FHR / Fernando Rial Villar
P. 53: Fraunhofer FHR / Thomas Bertuch
P. 54: Fraunhofer FHR / Uwe Bellhäuser
P. 57 Image 1: Fraunhofer FHR / Sabine Gütgemann, Image 2 / Image 3: IMS Messsysteme GmbH
P. 61: Fraunhofer MEVIS
P. 62: Shutterstock
P. 63: Fraunhofer FHR / Stefano Turso
P. 67: Fraunhofer MEVIS
P. 69: Shutterstock
P. 72 Fraunhofer FHR / Jens Fiege

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20 events were held in 2020 with an average of about 100 participants each, totaling over 900 people, many of whom attended multiple times. Over 93% rated the lectures as very good or good.

THE EVENTS ALWAYS TAKE PLACE ON TUESDAYS FROM 2:00 TO 2:30 PM. THEY INCLUDE LIVE PRESENTATIONS ON A RADAR APPLICATION – SOMETIMES INCLUDING LIVE DEMONSTRATION WITH THE HELP OF EXPERIMENTAL SYSTEMS AS WELL AS OPPORTUNITIES FOR QUESTIONS AND EXCHANGE. PARTICIPATION IS FREE OF CHARGE, ONLY REGISTRATION IS REQUIRED.

Many lectures from our "Radar in Action" online lecture series can now also be found on our YouTube channel:

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23.2.2021
High-resolution imaging with a 240-Ghz radar with SiGe chip
Referenten: Prof. Dr.-Ing. Nils Pohl, Dr.-Ing. Reinhold Herschel

2.3.2021
Parasol: Passive radar controls nighttime marking of wind turbines
Referenten: Dipl.-Ing. Jochen Schell, Marvin Friedrichsen (Parasol GmbH & Co. KG)

9.3.2021
Radar schützt Fußgänger – das HORIS-Projekt
Referent: Dr.-Ing. Reinhold Herschel

16.3.2021
Ballast Condition Assessment in modern railways using RADAR
Referenten: M. Sc. Thoetphan Kingsuwannaphong (RWTH Aachen), M. Sc. Stefan Rümmler

23.3.2021
Real-time SAR - live aerial imaging in all weather conditions
Referent: Dr. rer. nat. Stephan Stanko

20.4.2021
Danger from drones: Monitoring airports with millimeter wave radar
Referent: M. Sc. Winfried Johannes

27.04.2021
Synthese von Radarrohdaten in Verkehrsszenarien durch Raytracing
Referenten: M. Eng. Stefan Wald, Dr.-Ing. Thomas Dallmann

04.05.2021
Machine Learning for Radar applications - Classification of Targets using Neural Networks
Referent: Dr.-Ing. Simon Wagner

11.05.2021
TIRA als Sensor im Bereich Space Situational Awareness (SSA)
Referentin: M. Sc. Nora Egli

18.05.2021
DVB-S based passive radar imaging
Referentin: Dr. Iole Pisciottano

1.6.2021
Additive Herstellungsverfahren für Millimeterwellen-Komponenten
Referent: M. Eng. Alex Shoykhetbrod

8.6.2021
The HORIS Project – How radar helps to protect pedestrians
Referent: Dr.-Ing. Reinhold Herschel

15.6.2021
Bildgebende Materialanalyse – SAMMI 3.0
Referent: M. Sc. Sven Leuchs

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